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A HIGH RESOLUTION
SATELLITE COMMUNICATIONS MODEL

by

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Information warfare is a cornerstone of Joint Vision 2010 which addresses the future strategic environment for the United States. An integral component of information warfare is the continuing development of joint space doctrine. The Joint Warfare System (JWARS) is a large scale, systemic simulation being developed by the Joint Warfare Systems Office to aid in the evaluation of future joint doctrine and force structure. The purpose of this thesis is to develop and demonstrate Simulation of Satellite Communications (SIMSATCOM), a high resolution, stochastic simulation of satellite communications for evaluating the effectiveness of message transmission and receipt by specified senders and receivers. SIMSATCOM is designed to operate as a stand-alone simulation, but may be adopted as a high resolution module for a large scale simulation such as JWARS. The thesis describes SIMSATCOM in detail and provides analyses of simulation runs for different jamming levels and channel capacities.

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A HIGH RESOLUTION SATELLITE COMMUNICATIONS MODEL

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ABSTRACT

Information warfare is a cornerstone of Joint Vision 2010 which addresses the future strategic environment for the United States. An integral component of information warfare is the continuing development of joint space doctrine. The Joint Warfare System (JWARS) is a large scale, systemic simulation being developed by the Joint Warfare Systems Office to aid in the evaluation of future joint doctrine and force structure. The purpose of this thesis is to develop and demonstrate Simulation of Satellite Communications (SIMSATCOM), a high resolution, stochastic simulation of satellite communications for evaluating the effectiveness of message transmission and receipt by specified senders and receivers. SIMSATCOM is designed to operate as a stand-alone simulation, but may be adopted as a high resolution module for a large scale simulation such as JWARS. The thesis describes SIMSATCOM in detail and provides analyses of simulation runs for different jamming levels and channel capacities.

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EXECUTIVE SUMMARY

Information warfare is a cornerstone of Joint Vision 2010 which addresses the future strategic environment for the United States. An integral component of information warfare is the continuing development of joint space doctrine. The Joint Warfare System (JWARS) is a large scale, systemic simulation being developed by the Joint Warfare Systems Office to aid in the evaluation of future joint doctrine and force structure.

The purpose of this thesis is to develop and demonstrate Simulation of Satellite Communications (SIMSATCOM), a high resolution, stochastic simulation of satellite communications for evaluating the effectiveness of message transmission and receipt by specified senders and receivers. SIMSATCOM is designed to operate as a stand-alone simulation, but may be adopted as a high resolution module for a large scale simulation such as JWARS.

SIMSATCOM is written in Visual Basic for Applications using Microsoft Excel. The only user interface is prior to model execution, where input parameters are set. After initialization, the model selects the latitude and longitude values for both sender and receiver. Successful communication of each message from the sender to the receiver is based upon 1) message length, which is a function of the type of message transmitting; 2) whether the sender and/or receiver ground station is being totally jammed, partially jammed, or is not being jammed; and 3) satellite channel availability. There are ten stochastic variables in SIMSATCOM whose values are dynamically determined by Monte Carlo procedures using appropriate probability distributions.

After the simulation was developed, a demonstration case was run to show explicitly how the simulation works. Sample inputs were used, and four messages were selected to follow through one replication of the simulation. The case was run until message completion occurred for each of the four messages. Message completion indicates that 1) a message was transmitted successfully and an acknowledgment message was also transmitted successfully; 2) a message was transmitted successfully, but the acknowledgment message was not transmitted successfully; and after a period of time, the sender terminated the message process (this maximum time to transmit a message is a parameter input by the user prior to starting the model); and 3) a message was never transmitted successfully because it was jammed or there were no available channels, and the sender terminated the message process.

An example of the use of SIMSATCOM for analysis purposes is presented. A 2 x 2 factorial experiment, applying the analysis of variance, was run using channel capacity and anti-jam capability as the two factors. Five replications of the simulation were run for each case.

The model is a baseline high resolution communications simulation that can be expanded for future use. The model could be modified to make it more dynamic in terms of satellite locations; instrumental for a specified area of interest; making a more sophisticated jamming process; or as a baseline for other types of satellite models, such as near earth satellites or semi-synchronous satellites.

I. INTRODUCTION

Information warfare is a cornerstone of Joint Vision 2010 which addresses the future strategic environment for the United States. An integral component of information warfare is the continuing development of joint space doctrine. The Joint Warfare System (JWARS) is a large scale, systemic simulation being developed by the Joint Warfare Systems Office to aid in the evaluation of future joint doctrine and force structure.

The motivation for this thesis came from discussions with the JWARS office in Arlington, Virginia. They were interested in determining whether it would be adequate to model satellites aggregately in JWARS. There are many types of satellites that JWARS needs to consider; however, the focus of this thesis is to build a communications simulation that can be expanded to answer the geosynchronous satellite portion of this concern. (The Milstar satellites, used as a model for this thesis, are in inclined geostationary orbit approximately 22,400 nautical miles above the earth. [Ref. 17])

The purpose of this thesis is to develop and demonstrate Simulation of Satellite Communications (SIMSATCOM), a high resolution, stochastic simulation of satellite communications for evaluating the effectiveness of message transmission and receipt by specified senders and receivers. SIMSATCOM is designed to operate as a stand-alone simulation, but may be adopted as a high resolution module for a large scale simulation such as JWARS.

SIMSATCOM has many parameters that can be modified to answer several different questions. By adjusting one parameter and keeping the other parameters constant, n x m factor experiments can be conducted.

Possible questions that are addressed in Chapter V are:

> "What happens if the satellite capacity is increased?"
>
> "What happens if the anti-jam capability for a satellite is increased?"
>
> "Would it be better to buy more anti-jam capability or channel capacity for a satellite system?"

To answer these questions, two parameters are examined: the anti-jam capability parameter and the channel capacity parameter. These parameters are adjusted to determine if the number of good messages transmitted increases significantly for variations in the two factors. In Chapter V, a sparse 2 x 2 factorial experiment is presented to demonstrate how the model can be used to conduct analysis.

A background of existing simulations that utilize satellites is outlined in Chapter II. A description of how SIMSATCOM was developed and how it functions is given in Chapter III. Four sample messages are tracked through the model to show how each of the features of the model are used as depicted in Chapter IV. A small experiment was conducted to show how the model is used for analysis is illustrated in Chapter V. Finally, recommendations regarding how the model can be expanded and utilized for future use is described in Chapter VI.

II. BACKGROUND

In 1995 the Secretary of Defense tasked DoD to conduct a study to analyze the capabilities of current models and simulations. From this study the Deputy Secretary of Defense's Joint Analytic Model Improvement Program (JAMIP) was established. DoD developed JAMIP to help determine how to more effectively conduct joint theater-level analysis. Among other elements of JAMIP, the Joint Warfare System (JWARS) was conceptualized to satisfy this requirement. [Ref. 1: p.1]

JWARS will be the primary model used by the services for analysis. It will effectively model ground, air, naval, and space operations; command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR); strategic mobility; logistics; weapons of mass destruction; special operations; military operations other than war (MOOTW); and will appropriately represent the physical environment and its effect on simulated activities. [Ref. 1: p2, 5] It will operate at the theater, campaign and mission or small-unit level for joint analysis and will be able to model strategic, operational and tactical levels of war focusing at the operational level. [Ref. 1: p9] However, JWARS will not be interactive, will not support real-time mission execution or have any real-world direct links to any C4ISR systems. [Ref. 2: p2] The current plan is for JWARS Blocks I, II, and III versions to be developed by December 1998, December, 1999 and December, 2000 respectively. [Ref. 1: p9]

In order to correctly model space requirements there is a need to determine to what extent satellites should be modeled in the aggregate for the theater level models. Previous research conducted by Captain Robert Payne for his thesis in March 1995 reveals

that many of the primary models used by DoD for analysis do not include space assets [Ref. 3]. This chapter identifies theater-level models and some stand alone space models that exist today, and their characteristics.

A. OTHER MODELS

1. Integrated Theater Engagement Model (ITEM)

ITEM is a theater level, joint forces model designed to support joint warfare analysis, joint mission area assessments, major regional contingency scenario applications in joint wargames, and cost and operational effectiveness analysis, among others. The proponent for ITEM is the Navy (N81/DNA/SPAWAR 31). It currently models land, air, sea and undersea warfare. It models single and multiple engagements, and many-on-many, force-on-force and theater level warfare. It is a two-sided, deterministic, Monte-Carlo simulation that uses time step processing. Human participation is optional for decisions in this model. [Ref. 4]

2. Joint Theater Level Simulation (JTLS)

JTLS is a theater level model designed for analysis, development, and evaluation of operations plans [Ref. 5]. It also is used as a tool for force mix and resource analysis and as a high resolution wargame. JTLS models land, air, limited naval operations, intelligence and logistics. It is a multi-sided model that requires human participation for decisions and processes. JTLS can model from a single brigade to theater level warfare. It is a dynamic, event-step model that represents ground combat attrition deterministically, and air and naval attrition stochastically. JTLS requires human participation for decisions and processes. The proponent for JTLS is the Joint Warfare Center. [Ref. 6]

3. Mission Effectiveness Model (MEM)

MEM is a two-sided ballistic missile defense and ground-based Anti-Satellite (ASAT) analysis model. The proponent for MEM is the Headquarters, United States Air Force, Space Division. It focuses on nuclear ballistic missiles for offensive forces and non-nuclear weapons (e.g., directed energy, kinetic energy, and neutral particle beam weapons) for defensive forces. It also has the capability to model space-based interceptors, ballistic missiles, and ground-launched interceptors as well as communications, battle management, satellite attrition and sensor performance. MEM is a dynamic, time- and event-step model. It advances through events in user specified time increments. It is a stochastic model using Monte Carlo determination of results. MEM does not require human participation after the initial input and output file selection. [Ref. 7]

4. Joint Integrated Contingency Model (JICM)

JICM is a theater level, multi-sided, symmetric and reactive model used to support balance assessment, contingency analysis and is also used as a training tool. The proponent for JICM is the Director, Office of the Secretary of Defense / Net Assessment (OSD/NA). It models air and ground warfare in multiple theaters, naval warfare, strategic mobility, joint and combined operations, and limited NBC warfare. It is a deterministic and dynamic, time-step model. JICM can be used as stand alone or it can be utilized in an interactive mode if desired. [Ref. 8]

5. Space Communication Effectiveness Model (SpaceCEM)

SpaceCEM is an analysis model used to evaluate the performance of satellite communication systems. The proponent for SpaceCEM is the Air Force Electronic

Warfare Center, Special Studies Division. It models the effects of jamming, the environment, terrain and nuclear bursts on ground, air and space. It models satellite systems by a specific satellite or ground terminal. It is a one-sided, deterministic, dynamic, time- and event-step model. It requires human decisions for processes and the initial setup of each analysis. However, it is not an interactive model. [Ref. 9]

6. Space Forces Engagement Model (SFEM)

SFEM is an analysis model used as a research and evaluation tool for weapon systems development, systems effectiveness, force capability and requirements, mix effectiveness and resource planning. The proponent for the SFEM is Headquarters, Air Force Space Command. It models anti-satellite weapons and maneuver, decoy, and sabotage defenses. It is a two-sided, asymmetric, and dynamic event-step model. It can be run either as a stochastic (Monte Carlo) model or in a deterministic mode. Human interaction is not allowed. [Ref. 10]

7. SIGINT Analysis and Simulation System (SASS)

SASS is an analysis tool for current and projected signal environments and sensor systems operating in those environments. The proponent for SASS is Tactical Studies and Analysis, National Security Agency. It is a two-sided, theater-level model that models land, air, and naval operations. The collection simulation is one-sided. It can model emissions from the individual emitter level to a mix of collection systems. It is a dynamic time- and event- step model. It models the duty cycle of each emitter type stochastically using Monte Carlo techniques. It requires human decisions for data base input and analysis parameters. [Ref. 11]

8. TACWAR

TACWAR is a theater level model that is used primarily for OPLAN development and assessment by the CINC and by the Joint Staff for force structure sufficiency assessments. It is typically used as a course of action analyzer and a comparative analysis tool. It is a deterministic, two-sided, dynamic, time-stepped model that models air, land and sea. The model proponent is the Joint Staff, Force Structure, Resource, and Assessment Directorate (J-8), Automation Support Division. TACWAR requires human decisions as initial inputs and allows interruption for decision refinements. [Ref. 12]

9. THUNDER

THUNDER is a theater level warfare simulation model. It is used as a simulation to model conventional air, land and naval air warfare; evaluate force structures, conduct cost and operation effectiveness analyses and develop strategies and tactics, among other functions. The model proponent is the Air Force Studies and Analyses Agency (AFSAA/SAG). It is a two-sided model that can be run as a wargame or used as an analysis tool. It is a dynamic, time- and event- stepped model, using a Monte Carlo process to model aircraft kills. Ground attrition is modeled deterministically. No human participation is required, but are allowed if the simulation is interrupted. [Ref. 13]

B. SUMMARY

From the above and as was concluded from Captain Payne's thesis, there is no theater level simulation model that adequately models space. There are space "tools" that exist, but they are not sufficiently dynamic to be feeder models into theater and campaign level models. This thesis will focus on building a high resolution model that can be modified as a feeder model for low resolution models for analysis purposes.

III. SIMSATCOM METHODOLOGY

The basic attributes of SIMSATCOM are described in Section A. In Section B, the mathematical formulations, stochastic processes, and model products are described using the seven worksheets shown in Table 1. A logic flowchart and detailed description of the steps of the computer simulation, written in Visual Basic for Applications with Microsoft Excel, are provided in Appendix A.

A. OVERVIEW

The user initiates SIMSATCOM by defining the inputs for the simulation. These input parameters are described in Table 1 of Section B. After the user inputs the necessary parameters, the initialization portion of the simulation begins. Step 1 of the flow chart (Appendix A) describes the procedure of how the jammer locations are randomly generated. The user has the option to manually input the jammer locations into the "jammer" sheet and turn off the "setjammers" procedure in the reset portion of the program.

After the initialization, the new message generation process begins. Steps 12 through 20 in Appendix A describe how this process operates. The simulation uses a Poisson distribution to generate the number of messages sent for each message type for each time step. Step 14 describes how the program uses the lambda values, input by the user, to generate the number of messages for each message type. Several Uniform random numbers are also generated to create the following data for the new message:

- a new location for the sender and receiver; the sender and receiver type, which indicates the type of equipment the sender and receiver use to counteract jamming;

- the number of bits, which corresponds to the appropriate type of message;
- to determine if the message is transmitted using the low or medium data rate if the message is transmitted using satellites "3" or "4" (models of Milstar II).

The simulation next identifies which satellite(s) will be transmitting the data. The satellite(s) that transmit will depend on the sender and receiver locations. If the sender and receiver locations are not in the same transmission area for one satellite to transmit, then a crosslink is required, meaning that the more than one satellite is required to transmit the message. Both satellites must be available for the transmission to occur.

Jamming of the message may also occur at both the uplink and downlink locations of the transmission. There are three possible outcomes from the jamming process in the simulation. They are 1) "totally jammed" which means that the message was completely jammed; 2) "partially jammed" which means that the recipient received the message but the message was not comprehensible; and 3) "good" which means that the message was not jammed and the message was transmitted cleanly. Section B.5 describes how the jamming portion of the simulation works in more detail.

If there are available channels on the appropriate satellites and jamming does not occur on the transmission, then the message is transmitted. Otherwise the message waits in the retransmission queue for the appropriate time to retransmit.

After a message is sent, an acknowledgment message is transmitted. This acknowledgment message informs the sender that the message was received successfully and a retransmission is not necessary. If the acknowledgment message is not received by the sender, then the sender assumes that the message was not transmitted successfully and will retransmit the message again after a set period of time (an input by the user, based

upon the message type). The sender will only try to retransmit a message for a set period of time, after which the message transmission process stops.

B. WORKSHEETS

Seven worksheets are used in the model. The following section describes the worksheets that are used as data place holders. Table 1 summarizes each sheet function and the inputs that are necessary for initialization.

Sheet	Main Function Description	Input Items
sim	Contains sender and receiver locations, satellites used, type of message and status of message	average number of messages (lambda values) for each message type
sat chan	Contains the maximum number of satellites and the maximum number of channels per satellite	number of satellites maximum number of channels for each satellite
time	Contains satellite type and corresponding baud rates	
type	Contains conversion chart for: anti-jam capability wait time for sender to receive an acknowledgment message maximum time the sender will wait to send a message	anti-jam ability for each ground station type priority wait time for each message type maximum time to wait to retransmit for each message type
jammer	Contains jammer locations and whether the message is jammed	number of jammers "perJtot" value jammer latitude / longitude (optional, if input, turn off reset jammers procedure)
Retrans	Contains message information similar to "sim" sheet; used as a placeholder for the retransmission queue	
sat info	Contains satellite types and corresponding baud rates	satellite information

Table 1. Worksheet descriptions.

1. "sim"

The "sim" worksheet (Figure 1) is the principal worksheet used. The top portion of the sheet contains input and information placeholder data. The information placeholders include the *act row* cell which shows that the next available row on the

worksheet is row 194; the *cum time* cell which is the current time; and the *cum msgs* cell which denotes the number of messages that have been transmitted. The input values on this sheet are the *rate msg type* cells which are the lambda values. These values are the Poisson distribution input parameters, which are the average number of messages for each message type. These values are used in Step 14 of the flow chart presented in Appendix A utilizing the Poisson distribution shown in Equation 1.

$$F(x) = \begin{cases} 0 & \text{if } x < 0 \\ e^{-\lambda} \sum_{i=0}^{x} \frac{\lambda^i}{i!} & \text{if } 0 \le x \end{cases} \tag{1}$$

The next part of the "sim" worksheet contains the message information used in the model. Each row represents a message and the information that accompanies it. The first column represents the time step; the second column is the message number. A negative message number indicates that the message is an acknowledgment message to the absolute value of that number. The *message type* column indicates the type of message that is being transmitted. The possible values for this column are "1" (strategic message), "2" (tactical message), "3" (logistics message), or "4" (administrative message). The method used to fill this cell is explained in Step 16 of the flow chart (Appendix A). The number of bits to transmit corresponds to the type of message transmitting. The next four columns are the sender and receiver latitude and longitude locations. The procedure for how these are input is in Step 16 of the flow chart (Appendix A).

act row	194													
				input	rate msg type sent									
					lambda 1	2								
					lambda 2	3								
cum time	15				lambda 3	1								
cum msgs	147				lambda 4	3								
Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	rand # for data rate	sat type sender	sat type recvr	crosslink? 0-no 1-yes
0	0	0	0	1	1	1	1	0	0	0		1	1	0
1	1	2	4532	-81	253	-35	126	4	10	2	0.414644	3	2	1
1	2	3	27933	64	236	66	111	2	20	3	0.56177	3	2	1
1	3	3	28363	-68	348	-31	211	3	4	3	0.706453	4	3	1
1	4	3	14339	14	148	-89	30	4	19	3	0.704454	2	1	1

			(secs) (based on data rate)					
data rate	Up-baud	Cross-baud	TX- baud	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
LDR	1237.5	not cross	0					
LDR	1237.5	1237.5	3.662222	good				s1
LDR	1237.5	1237.5	22.57212	good				w
MDR	774400	774400	0.036626	j				w
LDR	1237.5	1237.5	11.58707	good				s

Figure 1. "sim" Sheet Extract.

The next two cells, the *send type* and *recv'r type* are used for the anti-jamming capability of the ground station. The value is a random integer between 0 and 20. The higher the number, the better the anti-jam capability (hence lower chance of being jammed). The explanation of Figure 4, the "type" worksheet provides additional information.

The *priority code* is currently set to the same value as the *message type*. This assumes that the smaller the message type value, the higher the priority of the message. The *random number for the data rate* is used for the *data rate* cell, which is explained in

the next paragraph. The satellite type sender and receiver columns, *sat type sender* and *sat type recvr*, identify which satellites are transmitting the data. Table 2 contains the characteristics and location for each satellite.

Satellite Number	Satellite Type	Longitude	Possible Baud Rate (*data rate* column)
1	A (Milstar I)	0 - 90	LDR
2	A (Milstar I)	90 - 180	LDR
3	B (Milstar II)	180 - 270	LDR / MDR
4	B (Milstar II)	270 - 360	LDR / MDR

Table 2. Satellite Characteristics.

To determine whether the LDR, "low data rate", or MDR, "medium data rate" is used, the random number generated earlier is compared to 0.15. This value was chosen because the Milstar II satellites have approximately 15% MDR channels (32 channels) and 85% LDR channels (192 channels). [Ref. 14] If the random number is less than 0.15 then MDR is input, otherwise the LDR is input.

The next two columns specify data rates. The values for these columns are the number of bits per second that the satellite can transmit. The *Up* column indicates the number of bits transmitting on the uplink. If there is a crosslink, then the value in the *crosslink* column will be the number of bits transmitting on both satellites; otherwise, the value in this column will be *no crosslink.*

The *TX-baud* value is a function of the bit rate and the message size. It is the total number of bits to transmit (located in the *bits to transmit* column discussed previously) divided by the number of bits per second the satellite is able to transmit.

The *jammed* column indicates whether the message was jammed. The possible values in this column are "good", indicating that the message was transmitted good, "j",

indicating that the message was not comprehensible due to jamming, or "pj", indicating that the message was partially jammed (i.e., the message header was comprehensible but the remaining portion of the message was not). Further explanation is given in the "jammer" sheet description.

The *ack msg* column is filled in only if the message is an acknowledgment message. The *retry* message column indicates that the message is a retransmission. If it is a retransmission, then the cell is filled with an "r". The *original message status* column is only utilized in conjunction with an acknowledgment message. The value in this column indicates how the original message was transmitted. It contains either the value "good" or "pj".

The final column, *msg sent*, is the final status of the message. Table 3 contains the possible values that could be entered in this column.

msg sent value	Meaning
"s"	message sent "good"; the sender received an acknowledgment message
"s1"	the message was sent "good" but the sender has not received an acknowledgment message
"s2"	the acknowledgment message was sent (this value corresponds only to an acknowledgment message)
"s3"	the message was successfully transmitted but was partially jammed
"w"	the message is in a waiting status (i.e., it is currently being processed or in the retransmission queue)
"j"	the message is jammed
"stopG"	The message process is complete for this message. The message was sent okay, but the sender never received an acknowledgment message and the maximum time to keep trying to send this message has been reached.
"stopNG"	The message process is complete. In this case the message was never received due to jamming, or not enough channels were available to transmit the message and the maximum time to keep trying to send the message was reached.

Table 3. Message Sent Column Possible Values

2. "sat chan"

The "sat chan" worksheet (Figure 2) contains the number of users that are currently utilizing the specified satellite. The model maintains this sheet to ensure that the satellite is not overloaded. The top portion of this sheet contains the maximum number of satellites and the maximum number of channels for each satellite. The *satellite available* row indicates if the satellite has any available channels to transmit messages. If the value is "False" then all channels are being used at that time. The next row value indicates the row that is available to input new information. The *current time* value indicates the current model time.

The *time* column shows the time corresponding to the satellite information in the adjacent columns. The *sat1 chan* column indicates whether a channel is being incremented or decremented on the satellite. The *cum sat* column indicates the cumulative number of channels being used on the satellite. These two columns are repeated for each satellite in the model.

	max # sats		4					
	max channel		8					
	sat	1		2		3		4
	max chan/sat	8		8		8		8
	sat avail?	FALSE		FALSE		FALSE		FALSE
Next row	106							
cur time	16							
time	sat1 chan	cum sat1	sat2 chan	cum sat2	sat3 chan	cum sat3	sat4 chan	cum sat4
	1	1	2	2	3	3	4	4
0		0		0		0		0
1		0	1	1	1	1		0
1		0	1	2	1	2		0
1	1	1	1	3		2		0

Figure 2. "sat chan" Sheet Extract.

3. "time"

The "time" worksheet (Figure 3) contains the message number that currently is being transmitted on a particular satellite. This sheet also keeps track of how much time that remains for each transmitting message. The columns on the "time" sheet are broken into categories by satellite. The first column is the current message transmitting on a channel on the specified satellite. The *time to transmit* column denotes the total amount of time that message will take to transmit. The *remaining time left on message number* column indicates the time that remains to transmit the message.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
39	3.10465	3.104646465	112	3.715556	0.715556	39	3.104646	3.104646	104	21.09495	17.09495
6	21.4505	7.450505051	2	22.57212	8.572121	2	22.57212	8.572121	22	29.08444	17.08444
116	32.1584	29.15838384	147	3.534545	3.534545	6	21.45051	7.450505	15	30.08566	17.08566
38	2.02667	0.026666667	-96	1.616162	0.616162	147	3.534545	3.534545	125	15.92646	13.92646
15	30.0857	17.08565657	22	29.08444	17.08444	-96	1.616162	0.616162	116	32.15838	29.15838
104	21.0949	17.09494949	128	27.60162	25.60162	124	17.61374	15.61374	34	26.61818	15.61818
75	19.7964	12.79636364	98	16.85414	11.85414	112	3.715556	0.715556	36	22.87434	11.87434
36	22.8743	11.87434343	34	26.61818	15.61818	98	16.85414	11.85414	128	27.60162	25.60162

Figure 3. "time" Sheet Extract.

4. "type"

The "type" worksheet (Figure 4) describes the anti-jam capability of the ground station. The current sender and receiver location and the sender and receiver type are from the active row on the "sim" sheet. These values are transferred to this worksheet by Step 49 in the flow chart (Appendix A).

Prior to the start of the model, the user inputs the proportions that correspond to the type. The proportions represent the anti-jamming capability of the ground station. For example, the sender in Figure 4 is type 8, which has a 0.4 anti-jam capability. The

probability that the ground station will be jammed is (1 - 0.4) times the probability of jam. The explanation of the "jammer" sheet provides further details.

This sheet also contains the amount of time the sender waits for the receipt of an acknowledgment message prior to retransmitting a message. The values "1", "2", "3", and "4" correspond to the priority of the message, and the wait time for each value is input by the user prior to execution of the model. The maximum wait time for retransmission is also input for each message priority class. This is the maximum amount of time the sender will keep trying to send the message.

		these are the current lat and long gets updated when run macro send recvr loc						
current	sender lat	-46	sender type					
	long	50	8					
	recvr lat	38	receiver type					
	long	331	1					
Type	proportion of anti-jam capability				Priority wait time for receipt of Ack			
1	0.05				1	6	secs	
2	0.1				2	10		
3	0.15				3	15		
4	0.2				4	50		
5	0.25							
6	0.3				Max Time for Retrans			
7	0.35				1	11		
8	0.4				2	30		
9	0.45				3	90		
10	0.5				4	200		
11	0.55							
12	0.6							
13	0.65							
14	0.7							
15	0.75							
16	0.8							
17	0.85							
18	0.9							
19	0.95							
20	1							

Figure 4. "type" Sheet Extract.

5. "jammer"

The "jammer" worksheet (Figure 5) contains the number of jammers that are capable of jamming a particular site. This sheet is used for every transmission to determine if the transmission was jammed. The top portion of the sheet contains the current sender and receiver location and the sender and receiver type from the active row on the "sim" sheet. These values are updated by Step 49 in the flow chart (Appendix A). The value *perJtot* is used to determine the portion of the jammed value that results in a partially jammed message, with (1- *perJtot*) resulting in a totally jammed message. The *maximum number of jammers* value is input by the user prior to the start of the model execution.

	these are the current lat and long							perJtot=	0.7		Max # of jammers	
current	sender lat	-46	sat type								9	
	long	50	8									
	recvr lat	38										
	long	331	1									
	Jammer Locations			uplink								
Barrier	lat	long	Max range of jammer	distance from jammer uplink	prob jam (uL)	perc jam	final P(jam) uL	jam none	jam partial	jam total	rand draw	type jam, 0-none,1-part, 2-total
RESULT					0.99752	0.6	0.598513	0.40149	0.58104	1	0.0711	0
1	-18	221	4336	18340.73617	0							
2	-21	182	7091	845.0255738	0.9858							
3	-57	300	6462	10058.62184	0							
4	-23	125	7636	13570.25114	0							
5	-10	328	4743	10708.9081	0							
6	-5	307	8042	18965.9238	0							
7	40	252	2808	1759.273846	0.60747							
8	-64	272	1948	5578.250762	0							
9	-14	8	5816	3877.799506	0.55545							

downlink								overall
dist from jammer (downlink)	prob jam (dL)	perc jam	final P(jam) dL	jam none	jam partial	jam total	rand draw	type jam, 0-none,1-part, 2-total
	0.992371	0.95	0.942752	0.0572	0.3401	1	0.527	2
10591.24898	0							
10873.55848	0							
2803.828525	0.811735							
10667.75358	0							
954.8089465	0.959475							
9448.192752	0							
9525.482223	0							
14810.82914	0							
14100.92044	0							

Figure 5. "jammer" Sheet Extract.

In the result portion of the worksheet, the top row is a consolidation of the jammers versus the sender and then the receiver. The first column represents the jammer number. The second and third columns represent the location of the jammer. The "Reset" procedure runs the "setjammers" routine, which assigns random locations for each of the jammers. This is explained further in Step 1 of the flow chart (Appendix A). The next column is the maximum range of the jammer. All of these values are input at the reset portion (Step 1) of the flow chart. The *distance from the jammer uplink* column determines how far the jammer is from the sender location. This value is calculated by the following equations: [Ref. 19]

$$dist = 2 * \rho * \arcsin(\frac{D}{2 * \rho}) \qquad (2)$$

with

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \qquad (3)$$

$$\begin{aligned} x_1 &= \rho * \sin(\phi_1) * \cos(\theta_1) \\ y_1 &= \rho * \sin(\phi_1) * \sin(\theta_1) \\ z_1 &= \rho * \cos(\phi_1) \end{aligned} \qquad (4)$$

$$\begin{aligned} x_2 &= \rho * \sin(\phi_2) * \cos(\theta_2) \\ y_2 &= \rho * \sin(\phi_2) * \sin(\theta_2) \\ z_2 &= \rho * \cos(\phi_2) \end{aligned} \qquad (5)$$

$$\phi_1 = \begin{cases} 90 - latitude1 & if\ latitude1 > 0 \\ 90 + latitude1 & otherwise \end{cases} \qquad (6)$$

$$\phi_2 = \begin{cases} 90 - latitude2 & if\ latitude2 > 0 \\ 90 + latitude2 & otherwise \end{cases} \qquad (7)$$

$$\theta_1 = 360 - longitude1 \qquad (8)$$

$$\theta_2 = 360 - longitude2 \qquad (9)$$

and ρ = 6367 km (the radius of the earth).

If the distance of the jammer to the sender is less than the maximum range of the jammer, the probability of jam for each individual location that is within range of the jammer is determined by the following formula which is from the ACES model [Ref. 3]:

$$P_{indiv.\ jammer}(jam) = 1\text{-}(dist/max\ Range)^2 \qquad (10)$$

Otherwise the probability of jam equals 0. The overall probability of jam is output in the *Result* row. The value of the initial probability of jam is:

$$P_{init}(jam) = 1\text{-}(1\text{-}Pjam\ (first\ jammer))*(1\text{-}Pjam\ (second\ jammer))*\ldots*(1\text{-}Pjam(nth\ jammer)) \qquad (11)$$

The *perc jam* value is based upon the type of anti-jam capability of the sender. The anti-jam effectiveness, which is used to compute the *perc jam* value, is computed and explained in Step 50 of the flow chart (Appendix A). The value of *perc jam* is:

$$perc\ jam = 1 \text{ - anti-jam effectiveness} \qquad (12)$$

The final probability of jam is now calculated as:

$$P_{final}(jam) = (P_{init}(jam)) * perc\ jam \qquad (13)$$

The *jam none*, *jam partial*, and *jam total* values are:

$$\begin{aligned} jam\ none &= 1 - P_{final}(jam) \\ jam\ partial &= P_{final}(jam) * (perJtot) \\ jam\ total &= P_{final}(jam) * (1 - perJtot) \end{aligned} \qquad (14)$$

A random number is then generated, as indicated in Step 50 of the flow chart, to determine whether the message is totally, partially or not jammed. If the random number is less than the *jam none* value then the transmission is not jammed and a "0" is entered; if the random number is between the *jam none* and the *jam partial* value then the transmission is partially jammed and a "1" is input. If the random number is greater than the *jam partial* value, then the transmission has been completely jammed and a "2" is input.

For the example, the sender is type 8, which corresponds to an anti-jam effectiveness of 0.4. The *perc jam* is 0.6 and the *final probability of jam* is 0.598 (0.997 * 0.6). The random number that was generated is 0.0711. This value is less than the *jam none* value (0.40149), so a "0" is entered in the *type jam* cell.

Because both the sender and receiver ground stations are susceptible to jamming, a similar calculation is needed for the downlink portion of the transmission. The computations for the downlink columns work similarly to the uplink columns. However, one difference is the calculation of the *type jam* column. This column is dependent upon the result of the uplink *type jam* column. If the result from the uplink *type jam* column is *jam total*, then the overall value for the *type jam* column is also *jam total*. If the uplink is *partially jammed*, the random number generated is only compared with the *jam none* value. If the random number is less than the *jam none* value, the value remains partially jammed (no jamming occurred on the downlink, but the message was partially jammed on the uplink so the overall evaluation is partially jammed); otherwise, the message is totally jammed. If the uplink was not jammed, then the calculation for this column is the same that was used for the uplink computation for *type jam*.

6. "Retrans"

The "Retrans" worksheet (Figure 6) contains the transmission information for the retransmission queue. The messages that are waiting for a retransmission are recorded on this sheet. The *time* column indicates the time the message was originally initiated. The *message number* column indicates the message number in the queue. The *message type, bits to transmit, send lat and long, receiver lat and long, send and receiver type*, and *priority code* columns are all copied from the "sim" sheet when the message gets initiated. Step 57 in the flow chart describes how these values are transferred from the "sim" sheet. The *wait time* value is input based upon the priority of the message, as described in Step 56 of the flow chart (Appendix A).

next mun	162												
				Sender		Receiver							
Time (in secs)	msg#	msg type	bits to transmit	Start Latitude	Start Long	End Latitude	End Long	send type	recv'r type	priority code	wait time	time to try again?	status
												0	
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good
2	9	1	3604	-25	257	75	112	13	11	1	6	14	good
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	stopNG

time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
						0
2	3	3	0.852068	good	11	13
8	3	2	0.631439	good	11	13
8	1	3	0.581526	j	11	13

Figure 6. "Retrans" Sheet Extract.

The *time to try again* value is the sum of the *wait time* and the *time last try msg* column. The *status* column indicates the status of the retransmission. "stopG", "stopNG" and "good" values indicate that the message will no longer be retransmitted. The value "stopG" means that the original message was sent successfully but the sender never

received an acknowledgment message. The "stopNG" value means that the message was never sent due to jamming or no channel was available. The value "good" indicates that the message and an acknowledgment message were transmitted successfully. The value "w" indicates the message is waiting to be retransmitted. The value "n" indicates that the message will not be retransmitted, (i.e., the message is a retry message and the original message is already in the queue). The *time last try message* column indicates the last time the message was attempted. The *satellite number up and down* columns indicate the satellite number that will transmit the message. The *random number* is the data rate random number from the "sim" worksheet. The *jammed* column indicates the original message jam status. The *maximum time to try* column is the maximum amount of time the sender will try to send the message. This is updated as indicated by Step 56 in the flow chart (Appendix A). The *time to stop trying* is the sum of the initial attempt to send the message (*time* column) plus the *maximum time to try* the message. This value indicates when the model will stop trying to send the message.

7. "sat info"

The "sat info" worksheet (Figure 7) contains the number and characteristics of satellites that are used. The satellites are modeled after the Milstar I and II satellites. The first column indicates that the Type "A" satellites (modeled after the Milstar I satellite) are "1", "2", "5", and "6" and Type "B" satellites (modeled after the Milstar II satellite) are "3", "4", "7", and "8". The second column indicates the satellite number. The data rate information shown in the next two columns gives the range for the low data rate, LDR, as 75 bits per second to 2,400 bits per second. The average is 1237.5 bits per second. For MDR, the range for transmission is from 4,800 to 1,544,000 bits per second. The average

rate is 774,400 bits per second. The average rates are the values used in the calculation on the "sim" sheet for the time to transmit a message.

		Data rates				
	Satellite		low	high	avg	
Type A	1	LDR	75	2400	1237.5	bps
1,2,5,6	2	LDR	75	2400	1237.5	bps
B	3	LDR	75	2400	1237.5	bps
3,4,7,8		MDR	4800	1544000	774400	bps
	4	LDR	75	2400	1237.5	bps
		MDR	4800	1544000	774400	bps

Figure 7. "sat info" Sheet Extract.

C. SUMMARY

After the program has run, statistical procedures were used to collect the data for analysis. An example run is shown in Chapter IV to show how the model works, and an example of how the model can be used for analysis is shown in Chapter V.

IV. DEMONSTRATION CASE

The Demonstration Case of the model is an initial verification run to ensure that all of the attributes in the model work as they were designed. Four messages are extracted from the Demonstration Case run to exhibit the various features. This chapter describes the features of the model in Section A, with the paths of the messages detailed in Section B. The paths of these messages explicitly describe how the model works.

A. FEATURES

There are several features in the model that are depicted as follows:

- Messages using an uplink only.

- Messages using a crosslink, i.e., an uplink and a downlink to transmit the message.

- Combinations of the original message and the acknowledgment message being transmitted "good", meaning no jamming interfered with the transmission; partially jammed, meaning some of the transmission was being jammed; or totally jammed, meaning that none of the message was received. For the partially jammed message, the assumption is that only the message header was able to transmit cleanly, meaning that the receiver obtained the message, but it was not comprehensible.

- The maximum time the sender waits to send a message. This occurs if a message has been on the retransmission queue for a specified amount of time and has not been transmitted. In this case the sender stops trying to resend the message and it is automatically taken off the queue.

- The maximum channel capacity of the model.

B. THE RUN

Messages 25, 27, 28, and 30 are tracked for the initial run. The features that each message cover in the model are shown in Table 4. As the run progresses, the entries will be updated.

Message	uplink only	uL & dL	original msg status	retry msg 1 status	ack msg	no avail chan, NAC	max time expired
25		X	j	good	j		X
27		X	j	j			X
28		X	NAC	good	good	X	
30	X		good		good		

Table 4. Summary of Features.

1. Input

Inputs to the Demonstration Case run are shown in Table 5.

sim sheet	sat chan sheet	type sheet		jammer sheet	program inputs
lambda 1= 2	max num of satellites = 4	proportion of anti-jam capability	from type 1 to type 20 start at 0.05 and increase by 0.95 for each type	max num of jammers = 9	num of iterations = 15
lambda 2 = 3	maximum number of channels on each satellite = 8	type of msg	wait time / max wait time		bits for type of message:
lambda 3 = 1		1	6 / 11		strategic = 2,000-4,000
lambda 4 = 3		2	10 / 30		tactical = 2,000-8,000
		3	15 / 90		logistic = 10,000-30,000
		4	50 / 200		admin = 20,000-50,000
					ack = 2,000

Table 5. Inputs for Demonstration Case Run.

2. Time Step 4

Figure 8 shows an extract of the “sim” sheet from iteration 4. Note that at time step 4, messages 25, 27, 28 and 30 are entered into the system. Message 25 is jammed, message 27 is partially jammed, message 30 is transmitted good, and there is not an available channel on satellite 2 for message 28 to be transmitted, indicated by no entry in

the *status* column. Messages 25, 27 and 28 are transmitted on different satellites for both the up and downlink and message 30 is transmitted using the same satellite for both the up and downlinks. Observe that in the *msg sent* column the status is "w" indicating that the message is waiting to be transmitted.

Figure 9 shows that messages 27 and 30 are transmitting on the appropriate satellites. Figure 10 shows an extract from the "Retrans" sheet after iteration 4. All four messages have been put on the retransmission queue, but Message 28 but will wait only one time step, and then try to retransmit. Note that the queue is sorted by the type of message and then by time.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				w
4	25	1	2015	40	86	-41	244	6	14	1	1	3	1.628283	j				w
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				w
4	27	1	3675	62	249	24	177	19	11	1	3	2	2.9697	pj				w
4	28	1	3807	25	240	29	41	15	14	1	3	1	3.076364					w
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					w
4	30	2	3062	-16	167	-10	154	15	15	2	2	2	2.4743	good				w
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w

Figure 8. "sim" Sheet Extract After Time Step 4.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	8.587070707	1	3.662222	0.662222	1	3.662222	0.662222	12	5.247677	3.247677
6	21.4505	18.45050505	2	22.57212	19.57212	2	22.57212	19.57212	22	29.08444	28.08444
11	2.7297	0.72969697	4	11.58707	8.587071	6	21.45051	18.45051	15	30.08566	28.08566
12	5.24768	3.247676768	9	2.912323	0.912323	26	0.002893	0.002893	24	1.785051	1.785051
15	30.0857	28.08565657	22	29.08444	28.08444	9	2.912323	0.912323	26	0.002893	0.002893
16	2.10343	1.103434343	24	1.785051	1.785051	16	2.103434	1.103434	36	22.87434	22.87434
36	22.8743	22.87434343	27	2.9697	2.9697	21	9.389899	8.389899			
			30	2.4743	2.4743	27	2.9697	2.9697			

Figure 9. "time" Sheet Extract After Time Step 4.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recv'r Lat	Recv'r Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.85207	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	8	w	2	3	2	0.63144	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	8	w	2	1	3	0.58153	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	w	2	1	1	0.35899	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	w	4	4	2	0.96841	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**10**	**w**	**4**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	w	4	3	4	0.59401	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**10**	**w**	**4**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**1**	**5**	**w**	**4**	**3**	**1**	**0.83**		**11**	**15**
1	1	2	4532	-81	253	-35	126	4	10	2	10	11	w	1	3	2	0.41464	good	30	31
2	12	2	6494	31	314	16	38	18	13	2	10	12	w	2	4	1	0.05753	good	30	32
2	13	2	6926	34	195	32	303	1	14	2	10	12	w	2	3	4	0.2702	j	30	32
3	16	2	2603	69	31	-29	216	16	5	2	10	13	w	3	1	3	0.46904	good	30	33
3	17	2	7230	77	276	90	347	13	7	2	10	13	w	3	4	4	0.79195	j	30	33
3	18	2	4311	73	358	61	230	8	7	2	10	13	w	3	4	3	0.17409	j	30	33
4	29	2	6572	-34	259	-20	293	8	17	2	1	5	w	4	3	4	0.30972		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**w**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**

Figure 10. "Retrans" Sheet Extract After Time Step 4.

3. Time Step 5

Figure 11 shows an extract from the "sim" sheet after iteration 5. Message 28 has been retransmitted at time step 5 and the *status* is now "good". Observe in Figure 12 that message 28 has been added to the "time" sheet satellite transmission. Notice in Figure 13 the *time since last try* column for the original message 28 has been updated. Also note that the row corresponding to message 28 at time step 5 is not in the queue due to the "n" in the *status* column.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				w
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**j**				**w**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s1
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**				**w**
~~4~~	~~28~~	~~1~~	~~3807~~	~~25~~	~~240~~	~~29~~	~~41~~	~~15~~	~~14~~	~~1~~	~~3~~	~~1~~	~~3.078364~~					~~w~~
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					w
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**w**
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w
									:									
									:									
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
~~5~~	~~28~~	~~1~~	~~3807~~	~~25~~	~~240~~	~~29~~	~~41~~	~~15~~	~~14~~	~~1~~	~~3~~	~~1~~	~~3.078364~~	~~good~~		~~r~~		~~w~~
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w

Figure 11. "sim" Sheet Extract After Time Step 5.

1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	7.587070707	34	26.61818	26.61818	-26	0.002583	0.002583	12	5.247677	2.247677
6	21.4505	17.45050505	2	22.57212	18.57212	2	22.57212	18.57212	22	29.08444	27.08444
-11	1.61616	1.616161616	4	11.58707	7.587071	6	21.45051	17.45051	15	30.08566	27.08566
12	5.24768	2.247676768				**28**	**3.0764**	**3.0764**	24	1.785051	0.785051
15	30.0857	27.08565657	22	29.08444	27.08444	29	5.310707	5.310707	29	5.310707	5.310707
16	2.10343	0.103434343	24	1.785051	0.785051	16	2.103434	0.103434	36	22.87434	21.87434
36	22.8743	21.87434343	**27**	**2.9697**	**1.9697**	21	9.389899	7.389899	-26	0.002583	-0.99742
28	**3.076**	**3.0763636**	**30**	**2.4743**	**1.4743**	**27**	**2.9697**	**1.9697**	34	26.61818	26.61818

Figure 12. "time" Sheet Extract After Time Step 5.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
1	1	2	4532	-81	253	-35	126	4	10	2	10	11	w	1	3	2	0.414644	good	30	31
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	8	w	2	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	8	w	2	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	w	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	w	4	4	2	0.968407	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**10**	**w**	**4**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	w	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**10**	**w**	**4**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**w**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
2	12	2	6494	31	314	16	38	18	13	2	10	12	w	2	4	1	0.05753	good	30	32
2	13	2	6926	34	195	32	303	1	14	2	10	12	w	2	3	4	0.270198	j	30	32
3	16	2	2603	69	31	-29	216	16	5	2	10	13	w	3	1	3	0.469038	good	30	33
3	17	2	7230	77	276	90	347	13	7	2	10	13	w	3	4	4	0.791947	j	30	33
3	18	2	4311	73	358	61	230	8	7	2	10	13	w	3	4	3	0.174092	j	30	33
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	w	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**w**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**

Figure 13. "Retrans" Sheet Extract After Time Step 5.

4. Time Step 7

Figure 14 shows that messages 27 and 30 have been sent at time step 7. The *status* column now indicates "s3" for message 27 and "s1" for message 30. Recall that "s3" indicates that the original message was a partially jammed message, and "s1" indicates that the original message was sent "good". Notice that messages -30 and -27 are being transmitted at time step 7. The negative value corresponds to the message that is being acknowledged.

Figure 15 shows the "time" sheet after time step 7. Messages 27 and 30 have been taken off the transmission queue. The acknowledgment messages -27 and -30 have been added. Note that there has been no change on the retransmission queue (Figure 16)

because the messages will not be removed until the acknowledgment messages have been received.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s1
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	j				**w**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**				**s3**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364					**w**
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					w
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**s1**
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w
5	-26	1	2000	54	308	5	228	15	11	4	4	3	0.002583	good	ack		good	s2
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364	**good**		**r**		**w**
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
6	56	4	31290	-57	0	71	227	7	3	4	1	3	25.28485					w
7	**-30**	**2**	**2000**	**-10**	**154**	**-16**	**167**	**15**	**15**	**4**	**2**	**2**	**1.6162**	**gooc**	**ack**		**good**	**t**
7	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**pj**	**ack**		**pj**	**pj**
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w

Figure 14. "sim" Sheet Extract After Time Step 7.

sat 1			sat 2			sat 3			sat 4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	5.587070707	34	26.61818	24.61818	**-27**	**1.6162**	**1.6162**	12	5.247677	0.247677
6	21.4505	15.45050505	2	22.57212	16.57212	2	22.57212	16.57212	22	29.08444	25.08444
62	24.1002	24.10020202	4	11.58707	5.587071	6	21.45051	15.45051	15	30.08566	25.08566
12	5.24768	0.247676768	-24	1.616162	0.616162	**28**	**3.0764**	**1.0764**	-24	1.616162	0.616162
15	30.0857	25.08565657	22	29.08444	25.08444	29	5.310707	3.310707	29	5.310707	3.310707
-16	1.61616	0.616161616	49	4.834747	3.834747				36	22.87434	19.87434
36	22.8743	19.87434343	**-30**	**1.6162**	**1.6162**	21	9.389899	5.389899	49	4.834747	3.834747
28	**3.076**	**1.0763636**	**-27**	**1.6162**	**1.6162**				34	26.61818	24.61818

Figure 15. "time" Sheet Extract After Time Step 7.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	8	w	2	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	8	w	2	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	w	4	4	2	0.968407	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**10**	**w**	**4**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**10**	**w**	**4**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**w**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.486628		11	18
7	58	1	2934	-34	197	81	162	18	5	1	1	8	w	7	3	2	0.143798		11	18
1	1	2	4532	-81	253	-35	126	4	10	2	10	11	w	1	3	2	0.414644	good	30	31
2	12	2	6494	31	314	16	38	18	13	2	10	12	w	2	4	1	0.05753	good	30	32
2	13	2	6926	34	195	32	303	1	14	2	10	12	w	2	3	4	0.270198	j	30	32
3	16	2	2603	69	31	-29	216	16	5	2	10	13	good	3	1	3	0.469038	good	30	33
3	17	2	7230	77	276	90	347	13	7	2	10	13	w	3	4	4	0.791947	j	30	33
3	18	2	4311	73	358	61	230	8	7	2	10	13	w	3	4	3	0.174092	j	30	33
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	w	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**w**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.543851		30	34

Figure 16. "Retrans" Sheet Extract After Time Step 7.

5. Time Step 9

Figure 17 shows an extract from the “sim” sheet after iteration 9. Message 28 has been transmitted “good” as indicated by the “s1” in *message sent* column of the original message 28 row. The corresponding acknowledgment message has been sent, which is indicated by message -28. The acknowledgment message -30 was sent as denoted by the “s2” in the *message sent* column. The message process for message 30 is now complete as indicated by the “s” in the *message sent* column. The message is also taken off the retransmission queue (Figure 19) as indicated by the “good” in the *status* column. Notice on the “time” sheet (Figure 18) that message -28 is added and messages -27 and -30 are removed. However, since message 27 was partially jammed, it is not taken off the retransmission queue (Figure 19) and the status does not change on the “sim” sheet *message sent* column.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**j**				**w**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**				**s3**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364					**s1**
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					w
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**s**
5	-1	2	2000	-35	126	-81	253	10	4	4	2	3	1.616162	j	ack		good	j
5	-26	1	2000	54	308	5	228	15	11	4	4	3	0.002583	good	ack		good	s2
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364	**good**		**r**		**w**
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
6	56	4	31290	-57	0	71	227	7	3	4	1	3	25.28485					w
7	**-30**	**2**	**2000**	**-10**	**154**	**-16**	**167**	**15**	**15**	**4**	**2**	**2**	**1.6162**	**good**	**ack**		**good**	**s2**
7	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**pj**	**ack**		**pj**	**s2**
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w
									:									
									:									
8	73	4	48874	-33	309	47	181	15	11	4	4	3	39.49414					w
9	**-28**	**1**	**2000**	**29**	**41**	**25**	**240**	**14**	**15**	**4**	**1**	**3**	1.616162	**good**	**ack**			**t**
9	-66	2	2000	-38	328	-75	217	4	20	4	4	3	0.002583	good	ack		good	t

Figure 17. “sim” Sheet Extract After Time Step 9.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	3.587070707	34	26.61818	22.61818	-28	1.6162	1.6162	-12	1.616162	0.616162
6	21.4505	13.45050505	2	22.57212	14.57212	2	22.57212	14.57212	22	29.08444	23.08444
62	24.1002	22.10020202	4	11.58707	3.587071	6	21.45051	13.45051	15	30.08566	23.08566
-12	1.61616	0.616161616	9	2.912323	1.912323	-66	0.002583	0.002583			
15	30.0857	23.08565657	22	29.08444	23.08444	29	5.310707	1.310707	29	5.310707	1.310707
-28	1.616	1.6161616	49	4.834747	1.834747	9	2.912323	1.912323	36	22.87434	17.87434
36	22.8743	17.87434343	82	33.31798	33.31798	21	9.389899	3.389899	49	4.834747	1.834747
83	34.1002	34.10020202	83	34.1002	34.1002	82	33.31798	33.31798	34	26.61818	22.61818
									-66	0.002583	-0.99742

Figure 18. "time" Sheet Extract After Time Step 9.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	14	w	8	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	w	8	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	good	4	4	2	0.968407	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**10**	**w**	**4**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**10**	**w**	**4**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**w**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.486628		11	18
									:											
									:											
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	w	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**good**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.543851		30	34

Figure 19. "Retrans" Sheet Extract After Time Step 9.

6. Time Step 10

Figure 20 shows an extract from the "sim" sheet after iteration 10. Message 25 is being retransmitted and is now being transmitted "good". Note the "r" in the *retry* column, indicating that the message is a retransmission. Message 25 has been updated in the retransmission queue (Figure 22). The *time since last try* column now shows "10", which indicates the last time this message was attempted was time step 10.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**j**				**w**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	27	1	3675	62	249	24	177	19	11	1	3	2	2.969697	pj				s3
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364					**s1**
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					w
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**s**
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w
									:									
									:									
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364	**good**		**r**		**w**
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
6	56	4	31290	-57	0	71	227	7	3	4	1	3	25.28485					w
7	**-30**	**2**	**2000**	**-10**	**154**	**-16**	**167**	**15**	**15**	**4**	**2**	**2**	**1.6162**	**good**	**ack**		**good**	**s2**
7	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**pj**	**ack**		**pj**	**s2**
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w
									:									
									:									
8	73	4	48874	-33	309	47	181	15	11	4	4	3	39.49414					w
9	**-28**	**1**	**2000**	**29**	**41**	**25**	**240**	**14**	**15**	**4**	**1**	**3**	1.616162	**good**	**ack**			**t**
9	-66	2	2000	-38	328	-75	217	4	20	4	4	3	0.002583	good	ack		good	s2
									:									
									:									
9	85	4	23485	86	59	-66	346	8	19	4	1	4	18.97778					w
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**good**		**r**		**w**
10	86	1	2745	-89	117	-90	113	16	8	1	2	2	2.218182					w

Figure 20. "sim" Sheet Extract After Time Step 10.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	2.587070707	34	26.61818	21.61818	**-28**	**1.6162**	**0.6162**			
6	21.4505	12.45050505	2	22.57212	13.57212	2	22.57212	13.57212	22	29.08444	22.08444
62	24.1002	21.10020202	4	11.58707	2.587071	6	21.45051	12.45051	15	30.08566	22.08566
25	**1.628**	**1.6282828**	9	2.912323	0.912323	**25**	**1.6283**	**1.6283**			
15	30.0857	22.08565657	22	29.08444	22.08444	29	5.310707	0.310707	29	5.310707	0.310707
-28	**1.616**	**0.6161616**	49	4.834747	0.834747	9	2.912323	0.912323	36	22.87434	16.87434
36	22.8743	16.87434343	82	33.31798	32.31798	21	9.389899	2.389899	49	4.834747	0.834747
83	34.1002	33.10020202	83	34.1002	33.1002	82	33.31798	32.31798	34	26.61818	21.61818

Figure 21. "time" Sheet Extract After Time Step 10.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	14	w	8	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	w	8	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	good	4	4	2	0.968407	good	11	15
4	25	1	2015	40	86	-41	244	6	14	1	6	10	w	10	1	3	0.2905	j	11	15
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**10**	**w**	**4**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**w**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.486628		11	18
7	58	1	2934	-34	197	81	162	18	5	1	1	8	w	7	3	2	0.143798		11	18
8	9	1	3604	-25	257	75	112	13	11	1	6		n		3	2	0.631439	good	11	
8	10	1	2561	-62	74	-44	201	2	20	1	6		n		1	3	0.581526	j	11	
8	63	1	3207	-12	165	41	153	8	4	1	1	9	w	8	2	2	0.219106		11	19
9	74	1	3789	8	323	52	88	13	11	1	1	10	w	9	4	1	0.610511		11	20
9	75	1	3499	-26	307	-77	75	12	2	1	1	10	w	9	4	1	0.049756		11	20
10	25	1	2015	40	86	-41	244	6	14	1	6		n		1	3	0.2905	good	11	
10	86	1	2745	-89	117	-90	113	16	8	1	1	11	w	10	2	2	0.718011		11	21
1	1	2	4532	-81	253	-35	126	4	10	2	10	11	w	1	3	2	0.414644	good	30	31
2	12	2	6494	31	314	16	38	18	13	2	10	12	good	2	4	1	0.05753	good	30	32
2	13	2	6926	34	195	32	303	1	14	2	10	12	w	2	3	4	0.270198	j	30	32
3	16	2	2603	69	31	-29	216	16	5	2	10	13	good	3	1	3	0.469038	good	30	33
3	17	2	7230	77	276	90	347	13	7	2	10	13	w	3	4	4	0.791947	j	30	33
3	18	2	4311	73	358	61	230	8	7	2	10	13	w	3	4	3	0.174092	j	30	33
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	w	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**good**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.543851		30	34

Figure 22. "Retrans" Sheet Extract After Time Step 10.

7. Time Step 11

The "sim" sheet (Figure 23) shows that message 27 is being retransmitted; however, it is being partially jammed. The acknowledgment message, message -28, has been sent as shown by the "s2" in the *message sent* column. The message process for message 28 is now complete as indicated by the "s" in the *message sent* column corresponding to the message 28 row and the "good" in the *status* column of the "Retrans" sheet (Figure 25). From the "time" sheet (Figure 24), message -28 has been removed and message 27 has been added. Message 27 has also been updated in the *time last try* column on the "Retrans" sheet (Figure 25) with the time, "11".

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**j**				**w**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	**27**	**1**	**3676**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**				**s3**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364					**s**
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					s1
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**s**
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w
									:									
									:									
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364	**good**		**r**		**w**
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
6	56	4	31290	-57	0	71	227	7	3	4	1	3	25.28485					w
7	**-30**	**2**	**2000**	**-10**	**154**	**-16**	**167**	**15**	**15**	**4**	**2**	**2**	**1.6162**	**good**	**ack**		**good**	**s2**
7	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**pj**	**ack**		**pj**	**s2**
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w
									:									
									:									
8	73	4	48874	-33	309	47	181	15	11	4	4	3	39.49414					w
9	**-28**	**1**	**2000**	**29**	**41**	**25**	**240**	**14**	**15**	**4**	**1**	**3**	1.616162	**good**	**ack**			**s2**
9	-66	2	2000	-38	328	-75	217	4	20	4	4	3	0.002583	good	ack		good	s2
									:									
									:									
9	85	4	23485	86	59	-66	346	8	19	4	1	4	18.97778					w
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**good**		**r**		**w**
10	86	1	2745	-89	117	-90	113	16	8	1	2	2	2.218182					w
									:									
									:									
11	-49	2	2000	-40	102	-28	355	8	4	4	2	4	1.616162	j	ack		good	j
11	**27**	**1**	**3676**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**		**r**		**w**
11	94	1	2923	36	316	-68	193	7	7	1	4	3	0.003775					w

Figure 23. "sim" Sheet Extract After Time Step 11.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	1.587070707	34	26.61818	20.61818	-29	1.616162	1.616162	-29	1.616162	0.616162
6	21.4505	11.45050505	2	22.57212	12.57212	2	22.57212	12.57212	22	29.08444	21.08444
62	24.1002	20.10020202	4	11.58707	1.587071	6	21.45051	11.45051	15	30.08566	21.08566
25	**1.628**	**0.6282828**	-9	1.616162	1.616162	**25**	**1.6283**	**0.6283**	97	2.128485	2.128485
15	30.0857	21.08565657	22	29.08444	21.08444	-9	1.616162	1.616162			
97	2.12848	2.128484848	**27**	**2.9697**	**2.9697**	**27**	**2.9697**	**2.9697**	36	22.87434	15.87434
36	22.8743	15.87434343	82	33.31798	31.31798	21	9.389899	1.389899			
83	34.1002	32.10020202	83	34.1002	32.1002	82	33.31798	31.31798	34	26.61818	20.61818

Figure 24. "time" Sheet Extract After Time Step 11.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
1	1	2	4532	-81	253	-35	126	4	10	2	10	21	w	11	3	2	0.41464382	good	30	31
2	8	1	2863	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.85206836	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	14	w	8	3	2	0.63143915	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	w	8	1	3	0.58152586	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.35898548	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	good	4	4	2	0.96840745	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**16**	**w**	**10**	**1**	**3**	**0.290484**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.59400517	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**17**	**w**	**11**	**3**	**2**	**0.375254**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**good**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.48662847		11	18
7	58	1	2934	-34	197	81	162	18	5	1	1	8	w	7	3	2	0.14379817		11	18
8	9	1	3604	-25	257	75	112	13	11	1	6		n		3	2	0.63143915	good	11	
8	10	1	2561	-62	74	-44	201	2	20	1	6		n		1	3	0.58152586	j	11	
8	63	1	3207	-12	165	41	153	8	4	1	1	9	w	8	2	2	0.21910638		11	19
9	74	1	3789	8	323	52	88	13	11	1	1	10	w	9	4	1	0.61051065		11	20
9	75	1	3499	-26	307	-77	75	12	2	1	1	10	w	9	4	1	0.04975599		11	20
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**		**n**		**1**	**3**	**0.290484**	**good**	**11**	
10	86	1	2745	-89	117	-90	113	16	8	1	1	11	w	10	2	2	0.71801072		11	21
11	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**		**n**		**3**	**2**	**0.375254**	**pj**	**11**	
11	94	1	2923	36	316	-68	193	7	7	1	1	12	w	11	4	3	0.97060937		11	22
11	95	1	3133	-51	340	66	197	7	11	1	1	12	w	11	4	3	0.25156766		11	22
1	1	2	4532	-81	253	-35	126	4	10	2	10	11	w	1	3	2	0.41464382	good	30	31
2	12	2	6494	31	314	16	38	18	13	2	10	12	good	2	4	1	0.05752975	good	30	32
2	13	2	6926	34	195	32	303	1	14	2	10	12	w	2	3	4	0.27019817	j	30	32
3	16	2	2603	69	31	-29	216	16	5	2	10	13	good	3	1	3	0.46903759	good	30	33
3	17	2	7230	77	276	90	347	13	7	2	10	13	w	3	4	4	0.79194731	j	30	33
3	18	2	4311	73	358	61	230	8	7	2	10	13	w	3	4	3	0.17409164	j	30	33
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	w	5	3	4	0.3097226		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**good**	**4**	**2**	**2**	**0.988907**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.54385132		30	34

Figure 25. "Retrans" Sheet Extract After Time Step 11.

8. Time Step 12.

At time step 12, message 25 has been sent. The "sim" sheet (Figure 26) shows an "s1" in the *msg sent* column indicating that the message was sent good. Message -25, the corresponding acknowledgment message, is now being transmitted but it is being jammed.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s
4	25	1	2015	40	86	-41	244	6	14	1	1	3	1.628283	j				s1
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	27	1	3675	62	249	24	177	19	11	1	3	2	2.9697	pj				s3
4	28	1	3807	25	240	29	41	15	14	1	3	1	3.076364					s
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					s
									:									
									:									
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	j
5	28	1	3807	25	240	29	41	15	14	1	3	1	3.076364	good		r		w
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
7	-30	2	2000	-10	154	-16	167	15	15	4	2	2	1.616162	good	ack		good	s2
7	-27	1	2000	24	177	62	249	11	19	4	2	3	1.6162	pj	ack		pj	s2
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w
									:									
									:									
8	73	4	48874	-33	309	47	181	15	11	4	4	3	39.49414					w
9	-28	1	2000	29	41	25	240	14	15	4	1	3	1.616162	good	ack			s2
9	-66	2	2000	-38	328	-75	217	4	20	4	4	3	0.002583	good	ack		good	s2
									:									
									:									
9	85	4	23485	86	59	-66	346	8	19	4	1	4	18.97778					w
10	25	1	2015	40	86	-41	244	6	14	1	1	3	1.628283	good		r		w
10	86	1	2745	-89	117	-90	113	16	8	1	2	2	2.218182					w
									:									
									:									
11	-49	2	2000	-40	102	-28	355	8	4	4	2	4	1.616162	j	ack		good	j
11	27	1	3675	62	249	24	177	19	11	1	3	2	2.9697	pj		r		w
11	94	1	2923	36	316	-68	193	7	7	1	4	3	0.003775					w
									:									
									:									
11	105	4	30332	-26	270	-11	263	10	3	4	4	3	0.039168					w
12	-25	1	2000	-41	244	40	86	14	6	4	3	1	1.6162	j	ack		j	j
12	106	1	2754	-13	60	51	190	4	7	1	1	3	2.225455	j				w

Figure 26. "sim" Sheet Extract after Time Step 12.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
4	11.5871	0.587070707	34	26.61818	19.61818	-29	1.616162	0.616162			
6	21.4505	10.45050505	2	22.57212	11.57212	2	22.57212	11.57212	22	29.08444	20.08444
62	24.1002	19.10020202	4	11.58707	0.587071	6	21.45051	10.45051	15	30.08566	20.08566
109	6.11879	6.118787879	-9	1.616162	0.616162	109	6.118788	6.118788	97	2.128485	1.128485
15	30.0857	20.08565657	22	29.08444	20.08444	-9	1.616162	0.616162			
97	2.12848	1.128484848	27	2.9697	1.9697	27	2.9697	1.9697	36	22.87434	14.87434
36	22.8743	14.87434343	82	33.31798	30.31798	21	9.389899	0.389899			
83	34.1002	31.10020202	83	34.1002	31.1002	82	33.31798	30.31798	34	26.61818	19.61818

Figure 27. "time" Sheet Extract After Time Step 12.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	14	w	8	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	w	8	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	good	4	4	2	0.968407	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**16**	**w**	**10**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**17**	**w**	**11**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**good**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.486628		11	18
									:											
									:											
9	75	1	3499	-26	307	-77	75	12	2	1	1	10	w	9	4	1	0.049756		11	20
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**		**n**		**1**	**3**	**0.2905**	**good**	**11**	
10	86	1	2745	-89	117	-90	113	16	8	1	1	11	w	10	2	2	0.718011		11	21
11	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**		**n**		**3**	**2**	**0.3753**	**pj**	**11**	
11	94	1	2923	36	316	-68	193	7	7	1	1	12	w	11	4	3	0.970609		11	22
									:											
									:											
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	good	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**good**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.543851		30	34

Figure 28. "Retrans" Sheet Extract After Time Step 12.

9. Time Step 15.

The final time step for the Demonstration Case run is time step 15. The message process for messages 25 and 27 are now complete; the maximum time that the sender will attempt to send these messages has transpired. The "stopG" in the *message sent* column of the "sim" sheet (Figure 29) and the *status* column of the "Retrans" sheet (Figure 31) indicate that message 25 was sent good, but the sender never received an acknowledgment from the receiver. The "stopNG" indicates that message 27 was never obtained by receiver; in this case it was due to the message being jammed. At this time step, the message process for the four messages being tracked is complete, either because the messages were transmitted good or because time expired.

Time (in secs)	msg#	msg type?	bits to trans	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	sat type sender	sat type recvr	time to trans bps	jammed?	ack msg?	retry from retrans?	original msg status (for ack msg)	msg sent? s-sent; w wait; j ack jammed; stopG msg g ack not good; stopNG msg notsent
0	0	0	0	1	1	1	1	0	0	0	1	1	0					
									:									
									:									
4	24	1	2209	64	347	-62	176	18	13	1	4	2	1.785051	good				s
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**j**				**stopG**
4	26	1	2240	5	228	54	308	11	15	1	3	4	0.002893	good				s
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**				**stopNG**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364					**s**
4	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707					s
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**2**	**2**	**2.4743**	**good**				**s**
4	31	2	2057	80	267	43	146	9	3	2	3	2	1.662222					w
									:									
									:									
5	-9	1	2000	75	112	-25	257	11	13	4	2	3	1.616162	j	ack		good	s2
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**3**	**1**	3.076364	**good**		**r**		**w**
5	29	2	6572	-34	259	-20	293	8	17	2	3	4	5.310707	good		r		w
									:									
									:									
6	56	4	31290	-57	0	71	227	7	3	4	1	3	25.28485					w
7	**-30**	**2**	**2000**	**-10**	**154**	**-16**	**167**	**15**	**15**	**4**	**2**	**2**	**1.6162**	**good**	**ack**		**good**	**s2**
7	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**pj**	**ack**		**pj**	**s2**
7	57	1	2339	-47	150	30	216	5	15	1	2	3	1.890101					w
									:									
									:									
8	73	4	48874	-33	309	47	181	15	11	4	4	3	39.49414					w
9	**-28**	**1**	**2000**	**29**	**41**	**25**	**240**	**14**	**15**	**4**	**1**	**3**	1.616162	**good**	**ack**			**s2**
9	-66	2	2000	-38	328	-75	217	4	20	4	4	3	0.002583	good	ack		good	s2
									:									
									:									
9	85	4	23485	86	59	-66	346	8	19	4	1	4	18.97778					w
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**1**	**3**	1.628283	**good**		**r**		**w**
10	86	1	2745	-89	117	-90	113	16	8	1	2	2	2.218182					w
									:									
									:									
11	-49	2	2000	-40	102	-28	355	8	4	4	2	4	1.616162	j	ack		good	j
11	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**3**	**2**	**2.9697**	**pj**		**r**		**w**
11	94	1	2923	36	316	-68	193	7	7	1	4	3	0.003775					w
									:									
									:									
11	105	4	30332	-26	270	-11	263	10	3	4	4	3	0.039168					w
12	**-25**	**1**	**2000**	**-41**	**244**	**40**	**86**	**14**	**6**	**4**	**3**	**1**	**1.6162**	**j**	**ack**		**j**	**j**
12	106	1	2754	-13	60	51	190	4	7	1	1	3	2.225455	j				w
									:									
									:									
14	-116	1	2000	85	317	-75	198	19	18	4	4	3	0.002583	good	ack		good	s2
14	**-27**	**1**	**2000**	**24**	**177**	**62**	**249**	**11**	**19**	**4**	**2**	**3**	**1.6162**	**j**	**ack**		**pj**	**j**
14	-97	2	2000	53	87	72	341	3	13	4	1	4	1.616162	j	ack		pj	j

Figure 29. "sim" Sheet Extract After Time Step 15.

sat			sat			sat			sat		
1			2			3			4		
cur msg # transmitting	time to transmit	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #	cur msg # transmitting	time	remaining time left on msg #
			34	26.61818	16.61818	143	2.340202	2.340202	142	2.873535	2.873535
6	21.4505	7.450505051	2	22.57212	8.572121	2	22.57212	8.572121	22	29.08444	17.08444
62	24.1002	16.10020202	142	2.873535	2.873535	6	21.45051	7.450505	15	30.08566	17.08566
109	6.11879	3.118787879	126	2.157576	1.157576	109	6.118788	3.118788	143	2.340202	2.340202
15	30.0857	17.08565657	22	29.08444	17.08444				118	2.74101	0.74101
126	2.15758	1.157575758	128	3.479596	2.479596	128	3.479596	2.479596	36	22.87434	11.87434
36	22.8743	11.87434343	82	33.31798	27.31798	118	2.74101	0.74101			
83	34.1002	28.10020202	83	34.1002	28.1002	82	33.31798	27.31798	34	26.61818	16.61818

Figure 30. "time" Sheet Extract After Time Step 15.

Time (in secs)	msg#	msg type	bits to transmit	Send Lat	Send Long	Recvr Lat	Recvr Long	send type	recv'r type	priority code	wait time	time to try again?	status	time last try Msg	sat # up	sat # down	rand # (from sim)	jammed?	Max time to try	Time to stop trying
2	8	1	2663	-19	223	83	196	8	16	1	6	8	good	2	3	3	0.852068	good	11	13
2	9	1	3604	-25	257	75	112	13	11	1	6	14	good	8	3	2	0.631439	good	11	13
2	10	1	2561	-62	74	-44	201	2	20	1	6	14	stopNG	8	1	3	0.581526	j	11	13
2	11	1	3378	5	26	6	14	10	19	1	6	8	good	2	1	1	0.358985	good	11	13
4	24	1	2209	64	347	-62	176	18	13	1	6	10	good	4	4	2	0.968407	good	11	15
4	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**	**16**	**stopG**	**10**	**1**	**3**	**0.2905**	**j**	**11**	**15**
4	26	1	2240	5	228	54	308	11	15	1	6	10	good	4	3	4	0.594005	good	11	15
4	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**	**17**	**stopNG**	**11**	**3**	**2**	**0.3753**	**pj**	**11**	**15**
4	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**	**11**	**good**	**5**	**3**	**1**	**0.83**		**11**	**15**
5	**28**	**1**	**3807**	**25**	**240**	**29**	**41**	**15**	**14**	**1**	**6**		**n**		**3**	**1**	**0.83**	**good**	**11**	
7	57	1	2339	-47	150	30	216	5	15	1	1	8	w	7	2	3	0.486628		11	18
									:											
									:											
9	75	1	3499	-26	307	-77	75	12	2	1	1	10	w	9	4	1	0.049756		11	20
10	**25**	**1**	**2015**	**40**	**86**	**-41**	**244**	**6**	**14**	**1**	**6**		**n**		**1**	**3**	**0.2905**	**good**	**11**	
10	86	1	2745	-89	117	-90	113	16	8	1	1	11	w	10	2	2	0.718011		11	21
11	**27**	**1**	**3675**	**62**	**249**	**24**	**177**	**19**	**11**	**1**	**6**		**n**		**3**	**2**	**0.3753**	**pj**	**11**	
11	94	1	2923	36	316	-68	193	7	7	1	1	12	w	11	4	3	0.970609		11	22
									:											
									:											
4	29	2	6572	-34	259	-20	293	8	17	2	10	15	good	5	3	4	0.309723		30	34
4	**30**	**2**	**3062**	**-16**	**167**	**-10**	**154**	**15**	**15**	**2**	**10**	**14**	**good**	**4**	**2**	**2**	**0.9889**	**good**	**30**	**34**
4	31	2	2057	80	267	43	146	9	3	2	1	5	w	4	3	2	0.543851		30	34

Figure 31. "Retrans" Sheet Extract After Time Step 15.

C. SUMMARY

Tables 6, 7, and 8 show a summary of the "sim", "time" and "Retrans" sheets, respectively, for message 27 at times 4, 7, 9, 10, 11, 14, and 15.

time	status
4	Message generation, *jammed* value = "pj"
7	*Msg sent* value changed to "s3", message -27 (acknowledgment message for message 27 is sent)
9	Message -27 has transmitted ("s2" value in *msg sent* col); Message 27 status has not changed since message was partially jammed and it needs to be retransmitted
10	There were no available channels (satellites 2 and 3 are at capacity) so no retransmission
11	Message retransmitted, *jammed* value = "pj", *retry from retrans* column value = "r"
14	Message -27 is jammed
15	Message process complete; msg sent value = "stopNG" indicated message was never transmitted successfully

Table 6. "sim" Sheet Summary for Message 27.

time	status
4	Added to "time" sheet queue, transmitting on satellites 2 and 3
7	Message 27 removed from "time" sheet queue, message -27 added
9	Message -27 removed from "time" sheet queue
11	Added to "time" sheet queue, transmitting on satellites 2 and 3
14	Message 27 removed from "time" sheet queue

Table 7. "time" Sheet Summary for Message 27.

time	status
4	Added to retransmission queue; *time to try again value* = 10, *time to stop trying* = 15
11	*Time to try again* value = 17, *time last try msg* = 11
15	*Time to stop trying* value = 15, *status* = "stopNG" a flag that the message process is complete for this message.

Table 8. "Retrans" Sheet Summary for Message 27.

This chapter described an example run with example input parameters. There are many parameters that can be changed to answer a variety of questions. Chapter V will choose two such parameters to show how the model can be used for data analysis to answer specific questions.

V. ANALYSIS

The purpose of this chapter is to state the measures of effectiveness, describe the cases that were analyzed and describe how the analysis was conducted. There are many model parameters that can be modified for analysis; however, the focus of this thesis is the examination of two parameters: anti-jam capability and the number of channels available per satellite, reflected in the MOEs defined in Section A below.

Four cases are examined to complete this analysis as follows:

- Case 1 (baseline model for the analysis) - the anti-jam capability and channel capacity are set at low levels (LL);
- Case 2 - the number of available channels is doubled from the baseline model, but the anti-jam capability remains low (HL);
- Case 3 - the anti-jam capability is increased from the baseline model, but the channel capacity remains low (LH);
- Case 4 - the number of channels is doubled and the anti-jam capability is increased from the baseline model (HH).

Model run results are described in detail in Section B. A 2 x 2 Analysis of Variance (ANOVA) is used in the analysis to compare these four cases. A detailed discussion of the analysis methodology and results are provided at Section C.

A. MEASURES OF EFFECTIVENESS (MOE)

To help answer the question, "Would it be better to buy a satellite system that has a better anti-jam capability or has more channel capacity?", the following measures of effectiveness are identified:

- The total number of good messages transmitted.

- The number of messages that were transmitted successfully, but were stopped because a successful acknowledgment message was not received before the maximum time to attempt transmission had expired (stopG).
- The number of messages that were never transmitted (either due to jamming or no available channels when the message process stopped) because the maximum time to attempt transmission had expired (stopNG).
- The average time to send a message, given that it was transmitted successfully.
- The proportion of good messages to the number of messages generated for each priority.

B. CASES

The cases were selected to determine if changing the model's parameters would cause a significant difference in the MOEs (i.e., if the anti-jam capability was increased, the number of channels was increased, or both were increased). The random number seed was set to a different value at the beginning of each run for each case. Each case was run 5 times for 60 simulated seconds for each run. For an Intel Pentium 133 MHz processor, each run takes approximately 2 hours and 30 minutes.

1. Case 1 (LL)

The input parameters for Case 1 are given in Table 9. Both factors that are being compared in Case 1 are set at (low, low) (i.e., the channel capacity is set at eight channels and the anti-jam capability is set at 0.25).

Figures 32 and 33 show the number of messages generated by priority over time and the average number of messages generated over time, respectively. These charts show that the number of messages generated from the Poisson Distribution for each type of message approach the respective lambda values given in Table 9. Appendix D (Figures 97 – 102) shows similar figures for Cases 2, 3 and 4 with similar results.

The total number of Case 1 messages that were transmitted successfully, "stopG" and "stopNG" over time are shown in Figure 34. The number of channels used for each satellite over time is shown at Figure 35, which shows that almost all of the channels on each satellite are being used. Similar graphs that show channel use by priority are included in Appendix C (Figures 77 – 81).

Figure 36 shows the average time to transmit a message for every good message transmitted by priority. As time increases, the time to transmit a message depends upon the priority of the message. Because the size of the message is based on the type of the message, the results correlate to the input parameters.

Figure 37 shows the proportion of good messages of each priority to the number of messages generated for each respective priority (i.e., number of priority 1 good messages / number of total priority 1 messages generated). The message with the higher priority will have a higher probability of being transmitted successfully. The output correlates to the model design which processes messages first by priority, followed by first-in, first-out.

"sim" sheet	"sat chan" sheet	"type" sheet		"jammer" sheet	Other
lambda 1 = 2	Maximum number of satellites = 4	Anti-jam ability	For each type = .25	Max num of jammers = 9	Num of iterations = 60
lambda 2 = 3	Maximum number of channels on each satellite = 8	Type of message	Wait time / max wait time		Bits for type of message
lambda 3 = 1		1	3 / 7		Strategic: 1,000 – 2,000
lambda 4 = 3		2	6 / 13		Tactical: 1,000 – 4,000
		3	9 / 19		Logistic: 4,000 – 6,000
		4	12 / 25		Administrative: 4,000 – 8,000
					Acknowledgment: 2,000
					Random number seeds Runs 1 – 5: 1973272912 281629770 20006270 1280689831 2096730329

Table 9. Baseline Input Parameters.

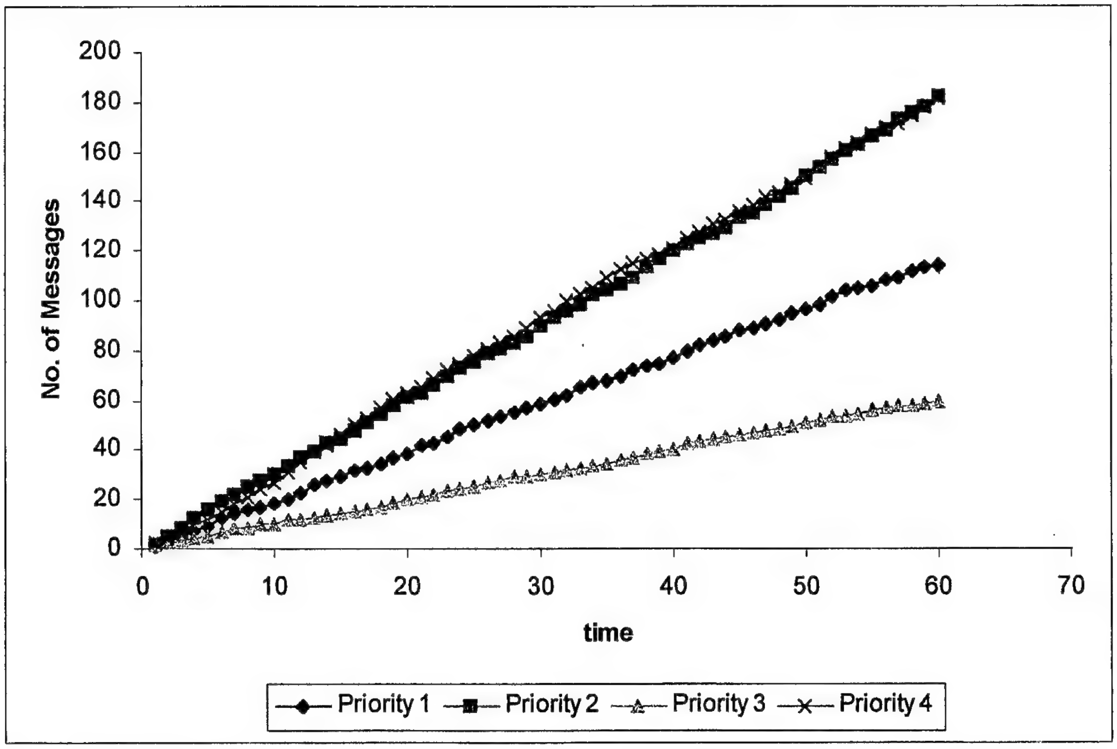

Figure 32. Case 1 (LL): Number of Messages Generated by Priority.

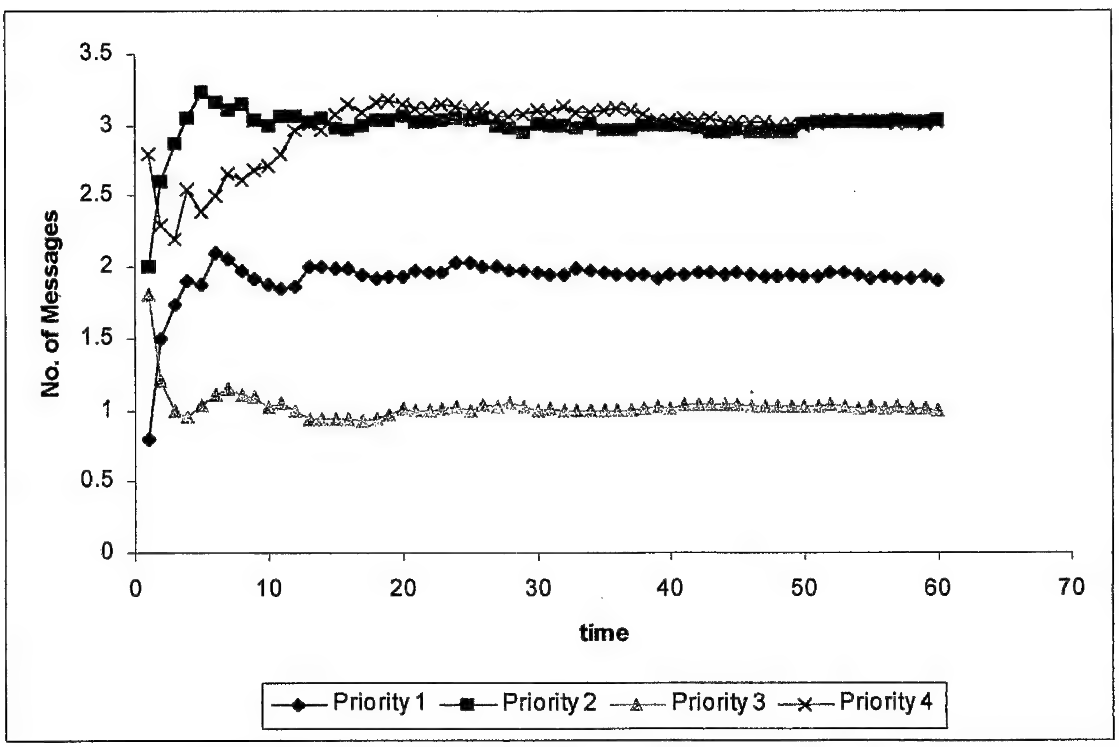

Figure 33. Case 1 (LL): Average Number of Messages Generated.

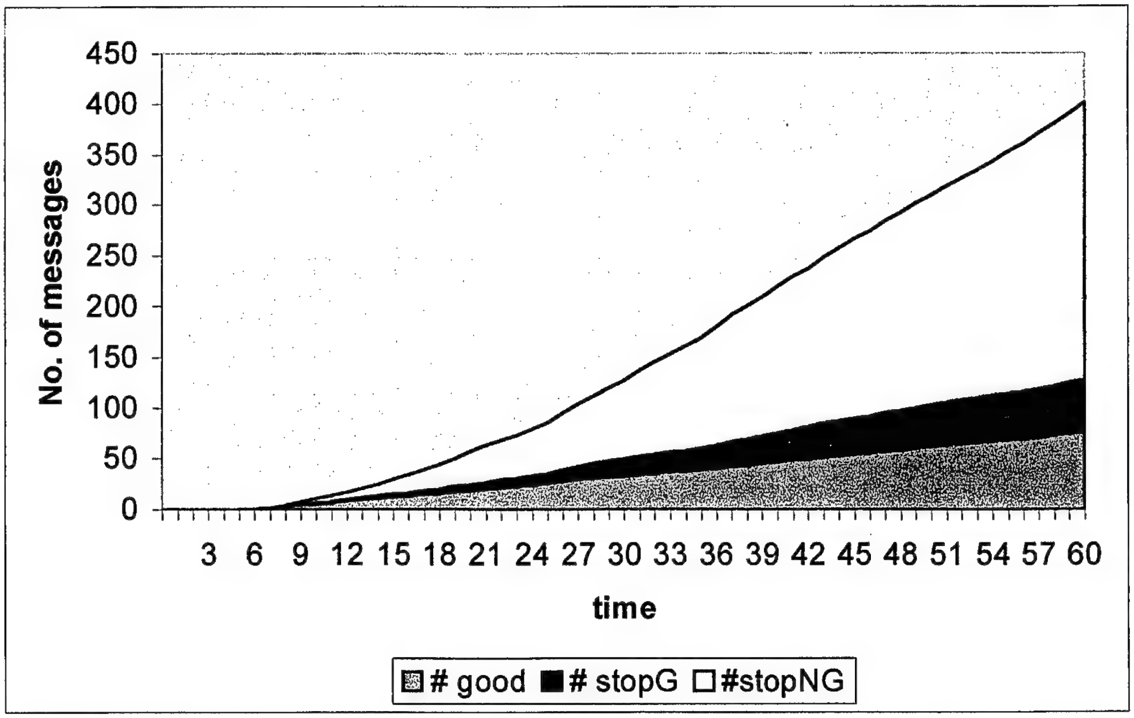

Figure 34. Case 1 (LL): Cumulative Message Status Summary.

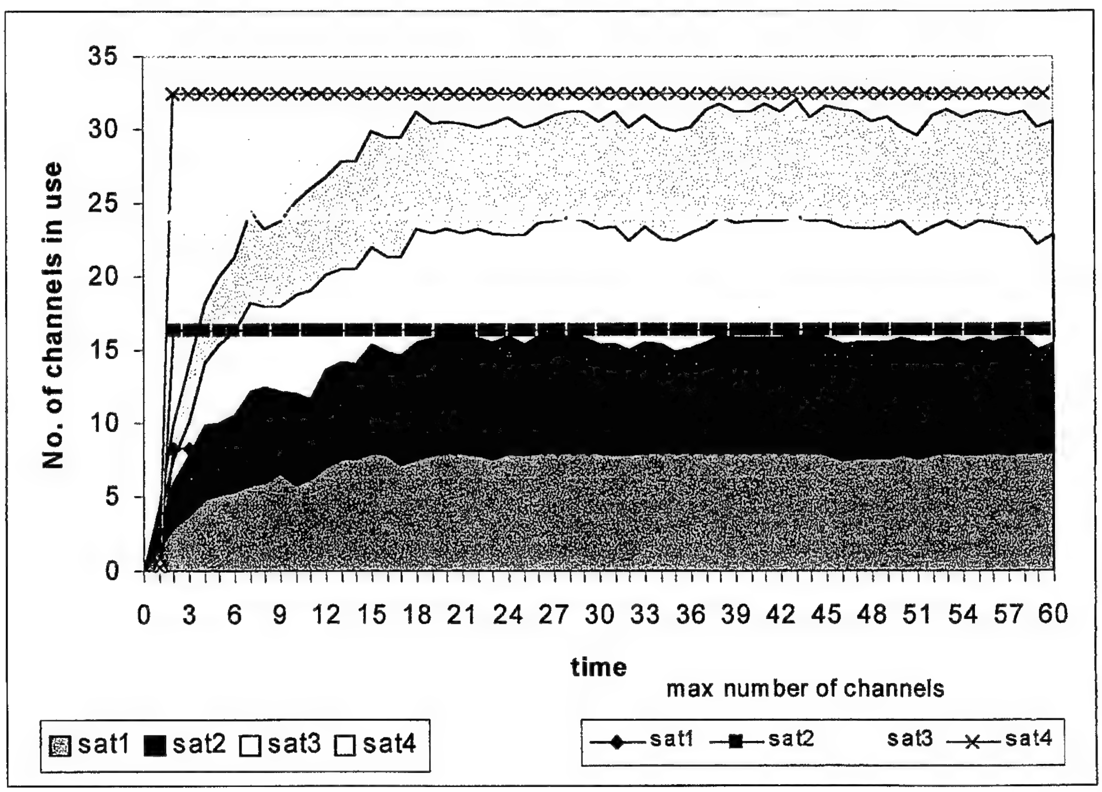

Figure 35. Case 1 (LL): Cumulative Number of Channels in Use Over Time.

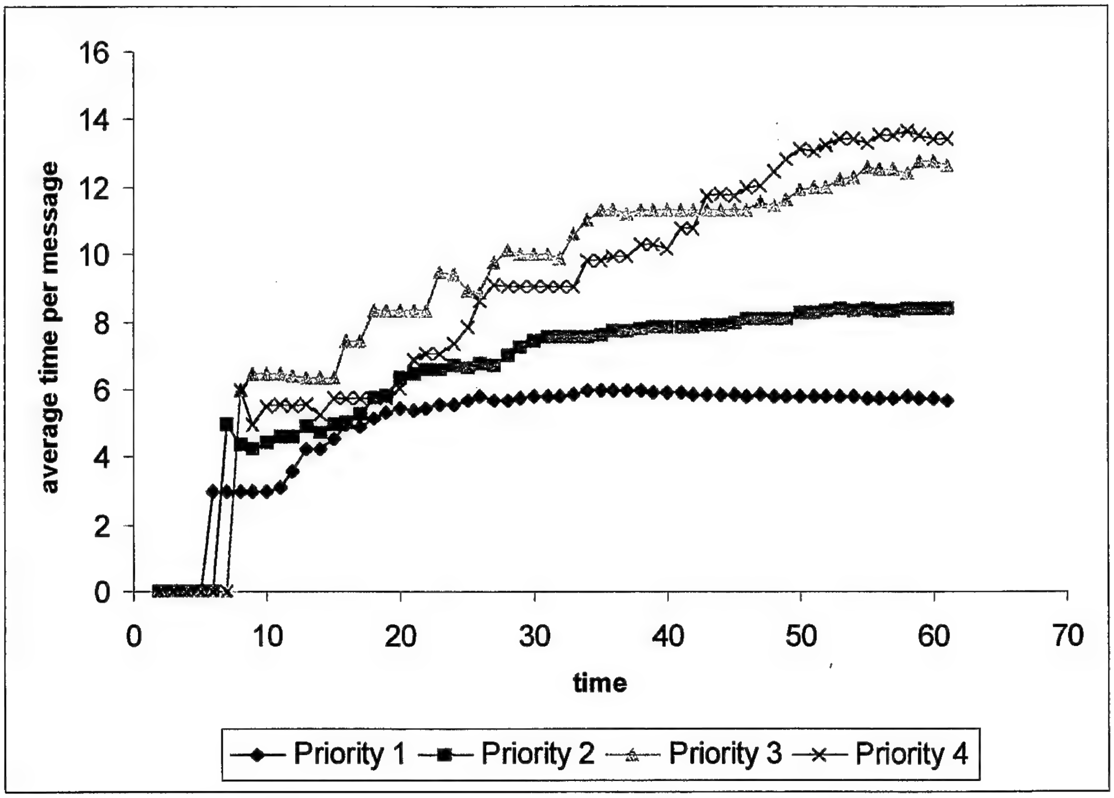

Figure 36. Case 1 (LL): Average Time to Transmit Good Messages.

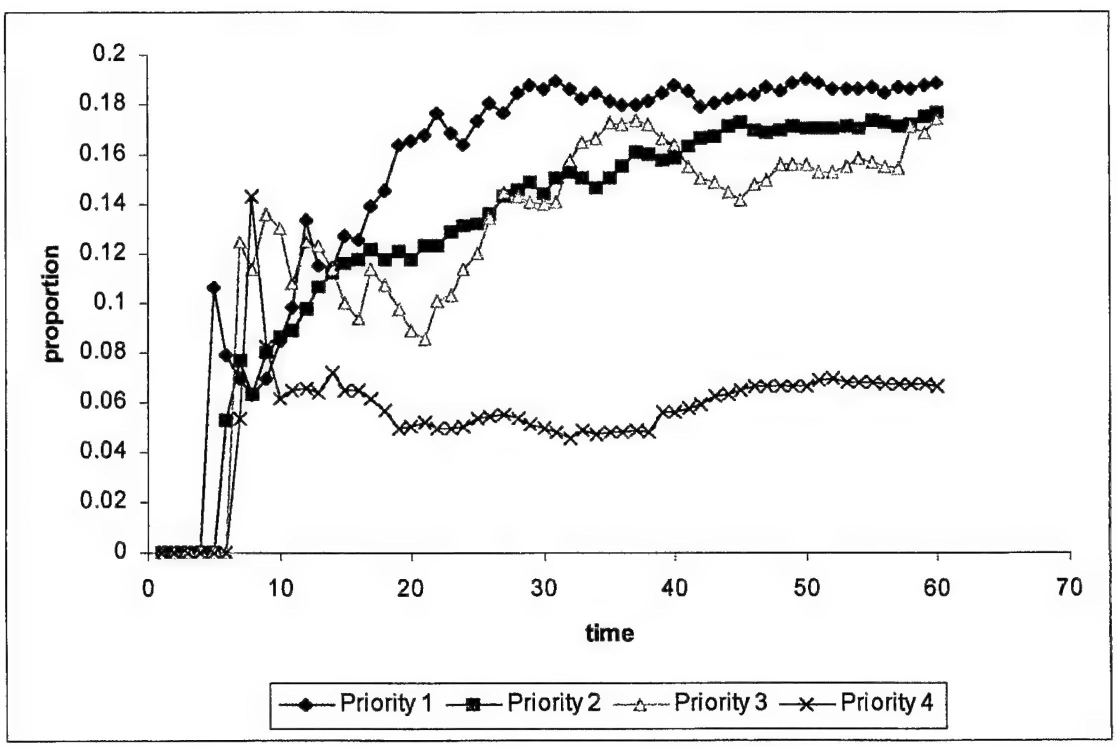

Figure 37. Cumulative Proportion of Good Messages to Number of Messages Generated by Priority.

2. Case 2 (HL)

The input parameters for Case 2 that were modified from Case 1 are channel capacity and the random number seeds for each run. The factors are now at (high, low) levels. The number of available channels on each satellite is increased from 8 to 16. The random number seeds for runs 1 – 5 were: 1933576050, 913566091, 246780520, 1363774876, and 604901985. All other input parameters remained the same as those in Case 1.

The total number of Case 2 messages that were transmitted successfully, "stopG" and "stopNG" over time are shown in Figure 38. Table 10 shows a comparison of good messages transmitted at different time intervals (the values are extracted from the number of good messages shown in Figures 34 and 38.) The number of good transmissions from Case 2 is at least 1.3 times greater than Case 1 at the specified time intervals.

The number of channels used for each satellite over time is shown at Figure 39. Similar graphs that show channel use by priority are included in Appendix C (Figures 76 – 80). Not all channels of all satellites are being used. This could be due to several factors: 1) at the time messages were being transmitted, they were being jammed; 2) one of the satellites required to be used to transmit a message was at full capacity, and the other satellite was available; or 3) satellites were available, but messages were in the wait portion of the retransmission queue. The lack of channels at full capacity is more apparent in Case 2 than Case 1 because each of the factors mentioned above is more pronounced in Case 2. In particular, there are more channels available in Case 2 and therefore, more chances for each of the factors to occur.

Figure 40 shows the average time to transmit a message for every good message transmitted by priority. Similar to Case 1, as time increases, the time to transmit depends upon the priority of the message. Because the size of the message is based on the type of the message, the results correlate to the input parameters. Compared to Case 1, the time to transmit priority 1, 2 and 3 messages went down slightly, but the time to transmit priority 4 messages increased slightly (0.2 seconds).

The proportion of good messages to the total number of messages is shown in Figure 41. The proportion has increased from Case 1 for all priorities.

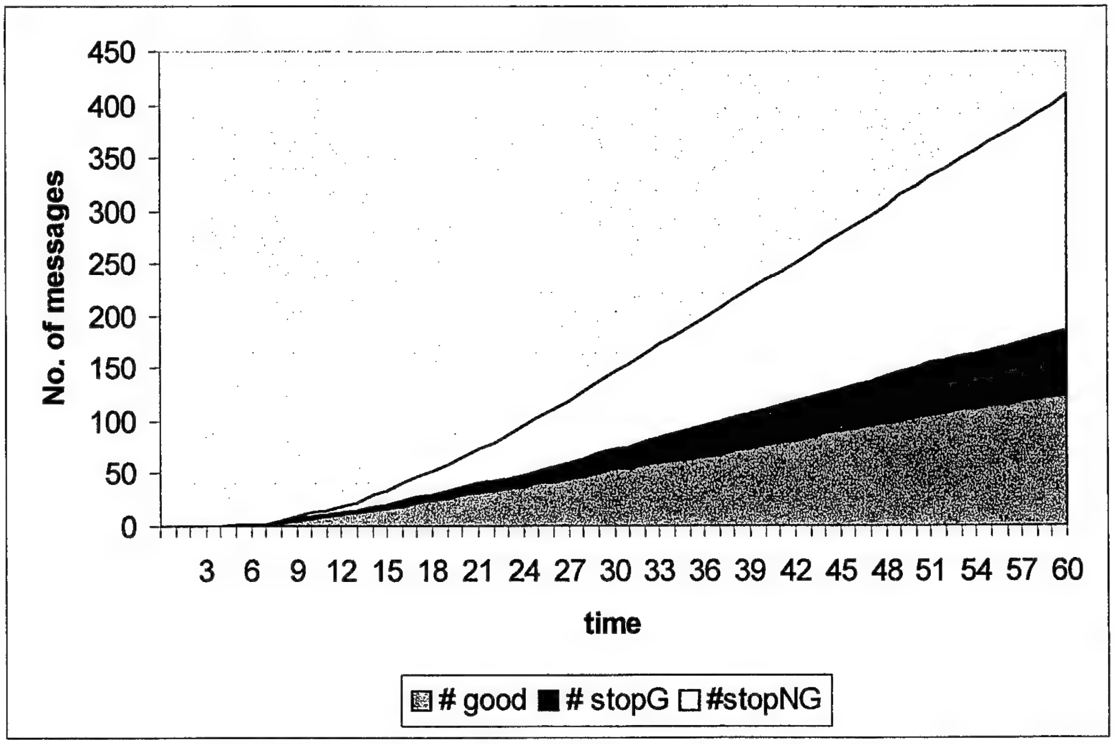

Figure 38. Case 2 (HL): Cumulative Message Status Summary.

Time (seconds)	Number of Good Message Transmissions		Proportion Increase in Number of Good Transmissions in Case 2 Over Case 1
	Case 1	Case 2	
15	12.8	17.4	1.36
30	32.8	54.2	1.65
45	54.6	89.8	1.64
60	76.2	125.2	1.64

Table 10. Good Message Transmission Time Comparison for Cases 1 (LL) and 2 (HL).

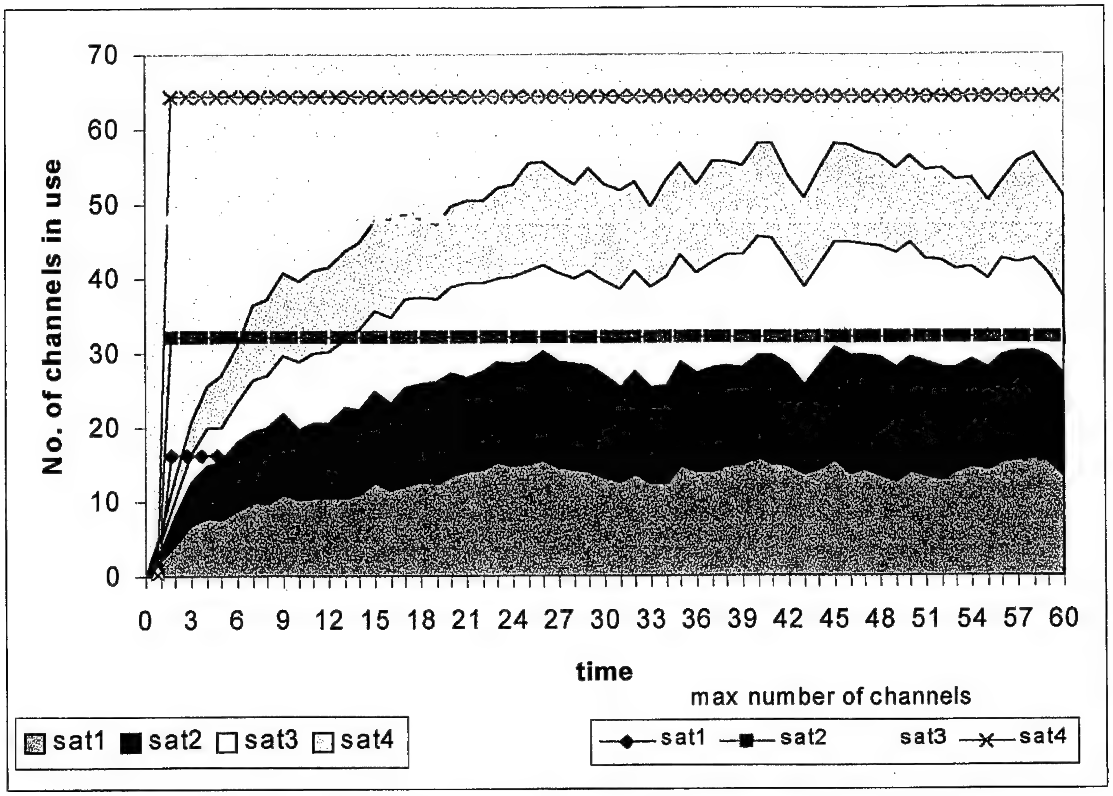

Figure 39. Case 2 (HL): Cumulative Number of Channels in Use Over Time.

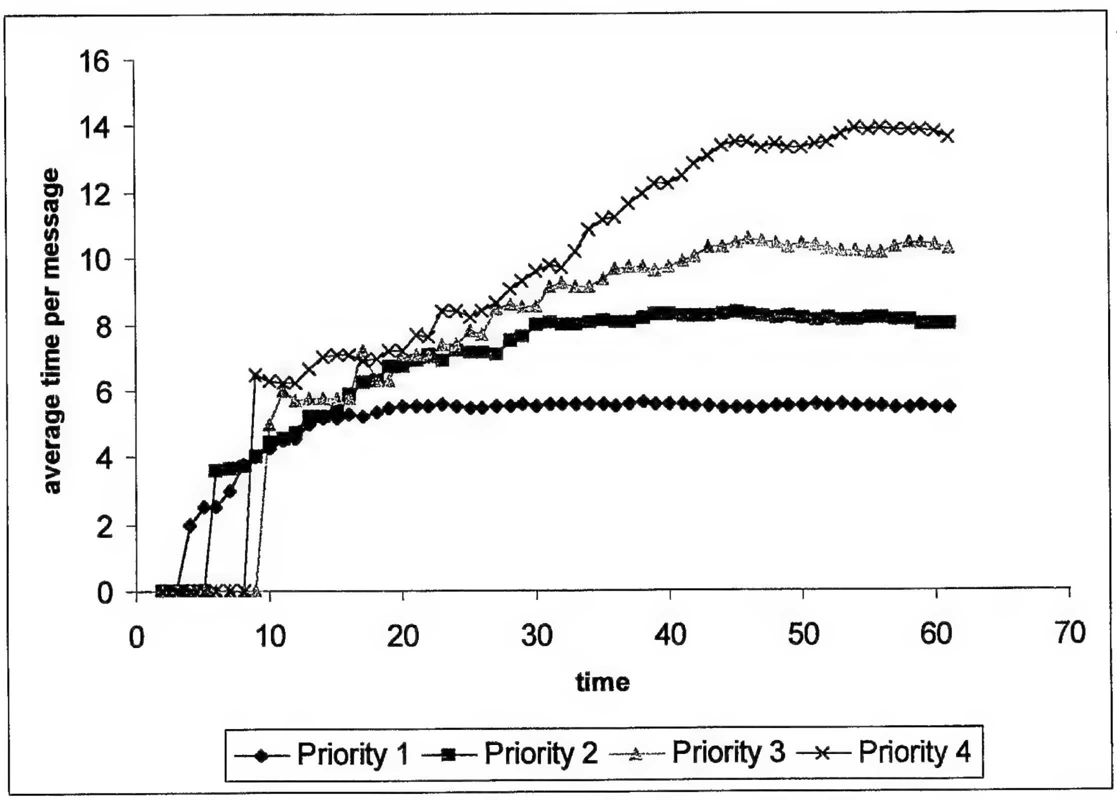

Figure 40. Case 2 (HL): Average Time to Transmit Good Messages.

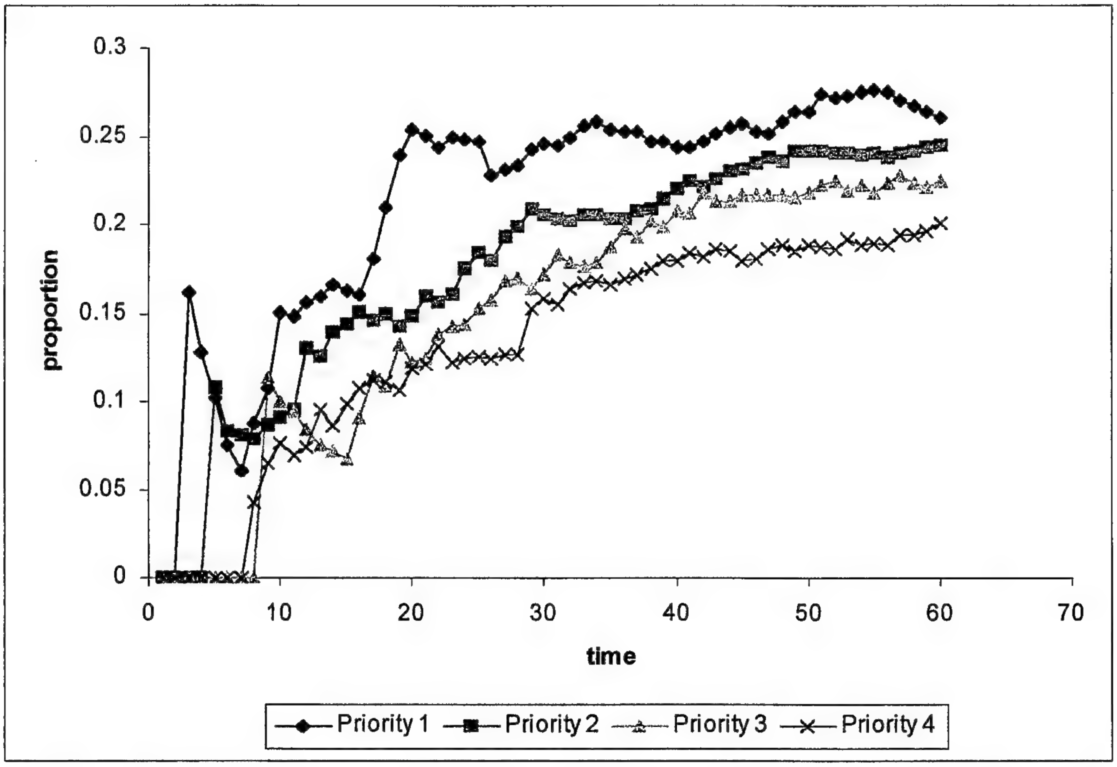

Figure 41. Cumulative Proportion of Good Messages to Number of Messages Generated by Priority.

3. Case 3 (LH)

The input parameters that were changed from Case 1 for Case 3 are the anti-jam capability and the random number seeds for each run. The factors are now at (low, high) levels. The satellite capacity is eight channels (low), the anti-jam ability for each type was changed from 0.25 to 0.75 (high) and the random number seeds for runs 1 – 5 were: 1511192140, 1259851944, 824064364, 150493284, and 242708531. All other input parameters remained the same as Case 1.

The total number of Case 3 messages that were transmitted successfully, "stopG" and "stopNG" over time are shown in Figure 42. Table 11 shows the values for the number of good messages transmitted at 15 second increments. The number of good messages transmitted has increased over 2.5 times from Case 1 (after 6 initialization seconds).

The number of channels used for each satellite over time is shown at Figure 43. Similar graphs that show channel use by priority are included in Appendix C (Figures 87 – 91). Figure 43 shows an approximately horizontal line for all satellites, which indicates that almost all of the channels are in use as in Case 1.

Figure 44 shows the average time to transmit a message for every good message transmitted by priority. Similar to Case 1, as time increases, the time to transmit depends upon the priority of the message. Because the size of the message is based on the type of the message, the results correlate to the input parameters. The time to transmit priority 1, 2 and 4 messages increased, and the time to transmit priority 3 messages decreased. The increased time to transmit messages may be due to more messages in the retransmission queue that will be sent successfully, when the opportunity for transmission occurs. The analysis of variance discussed later shows that there is no statistical significance to these results.

The proportion of good messages to the number of messages generated for each priority is shown in Figure 45. The proportion has increased from Case 1 for all priorities. The proportion of priority 1 and 2 good messages transmitted rose substantially compared to Case 1. The proportion of priority 3 and 4 good messages transmitted did not increase substantially compared to Case 1. This is because the maximum time expired before there was a channel available to transmit them (see Appendix B; Figures 69 – 70 did not change substantially compared to Figures 59 - 60).

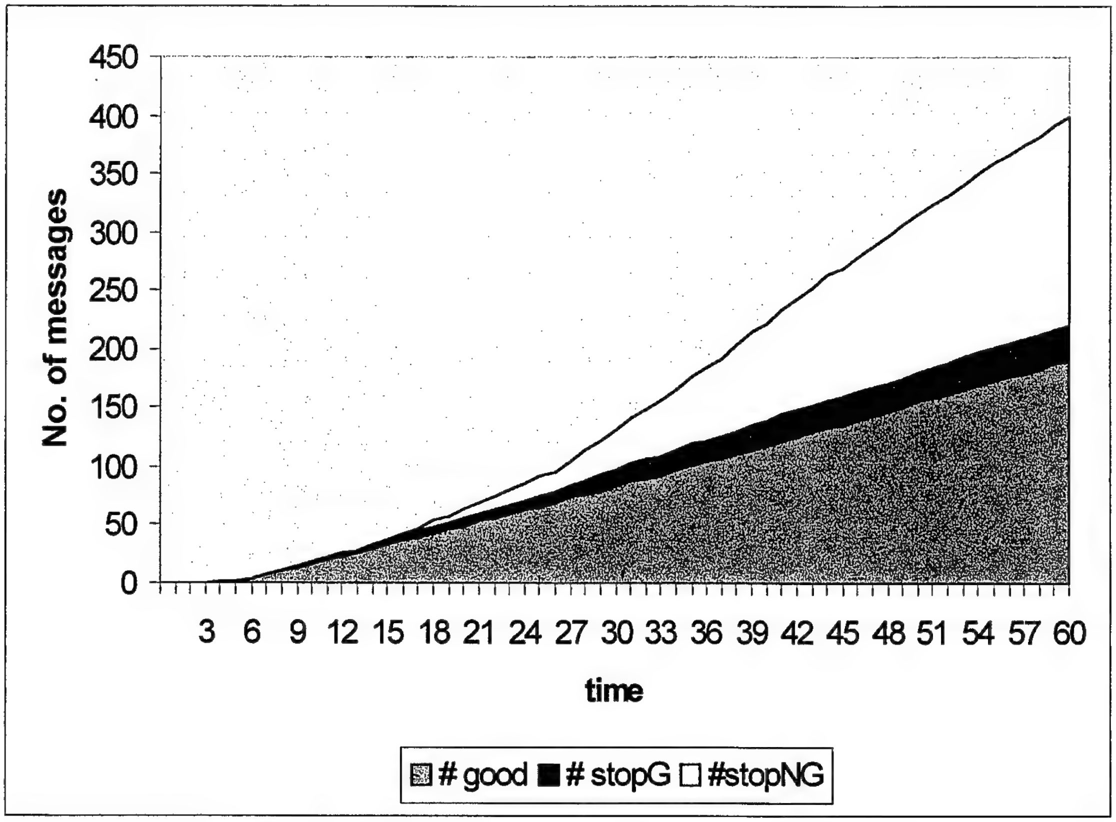

Figure 42. Case 3 (LH): Cumulative Message Status Summary.

Time (seconds)	Number of Good Message Transmissions		Proportion Increase in Number of Good Transmissions in Case 3 Over Case 1
	Case 1	Case 3	
15	12.8	33.2	2.6
30	32.8	84.2	2.8
45	54.6	136.2	2.5
60	76.2	190.4	2.5

Table 11. Good Message Transmission Time Comparison for Cases 1 (LL) and 3 (LH).

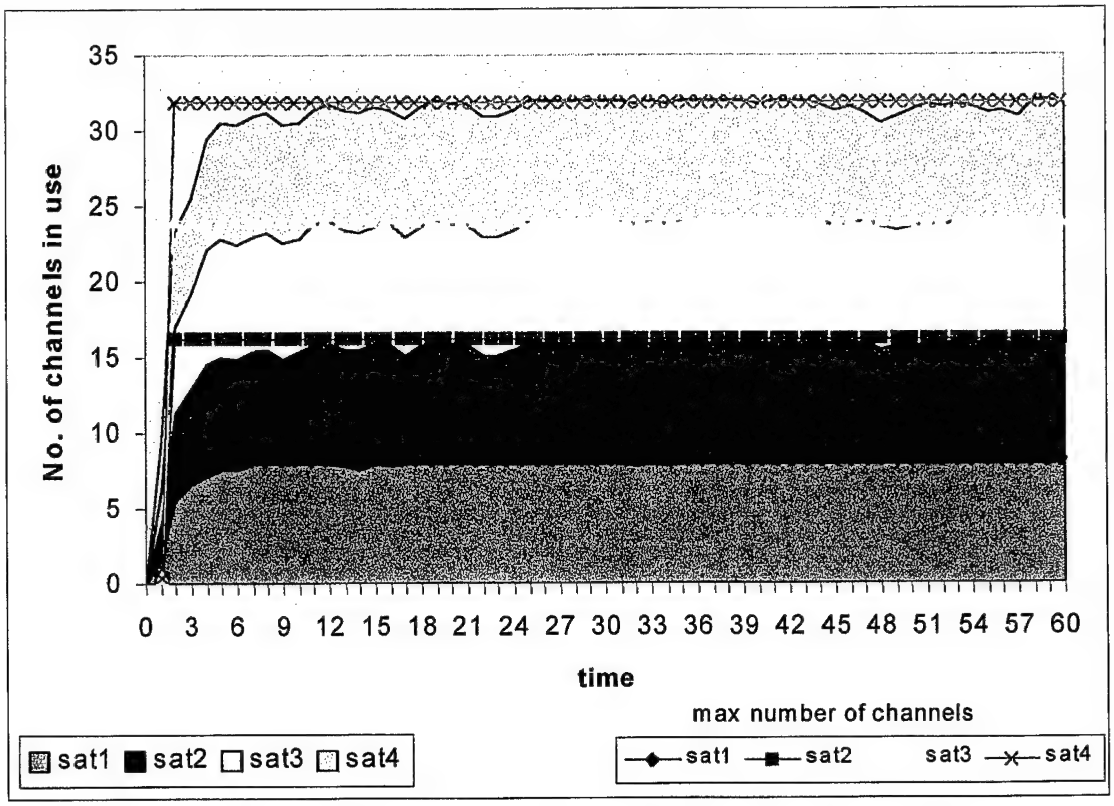

Figure 43. Case 3 (LH): Cumulative Number of Channels in Use Over Time.

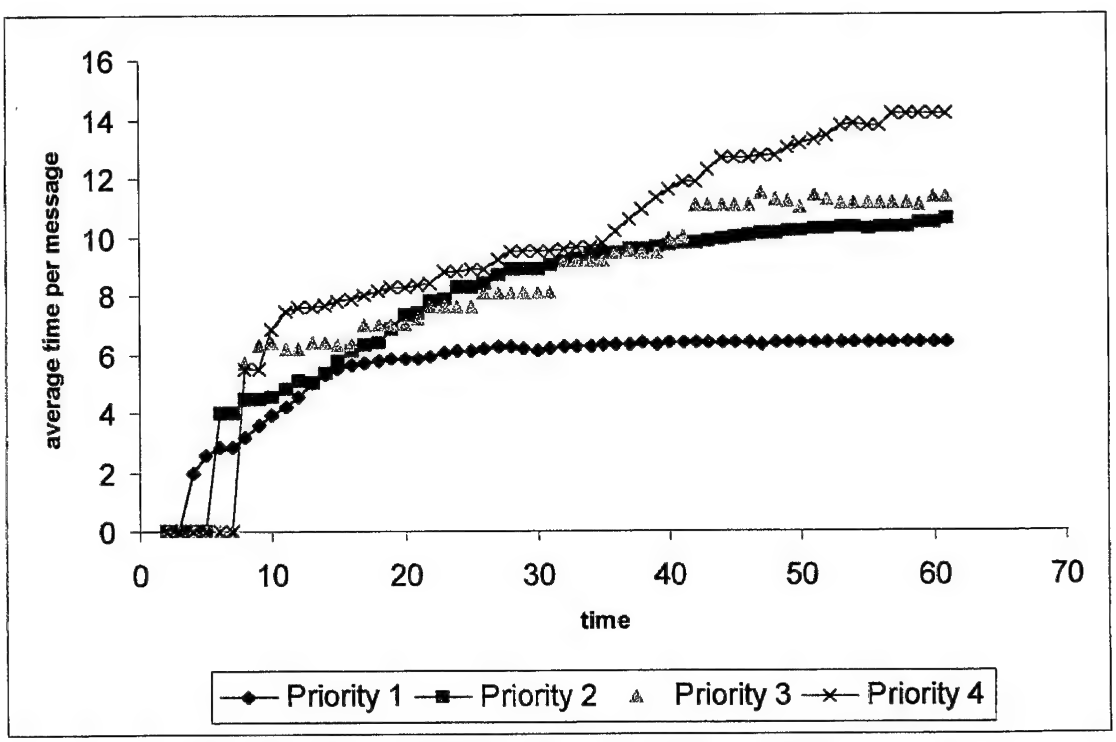

Figure 44. Case 3 (LH): Average Time to Transmit Good Messages.

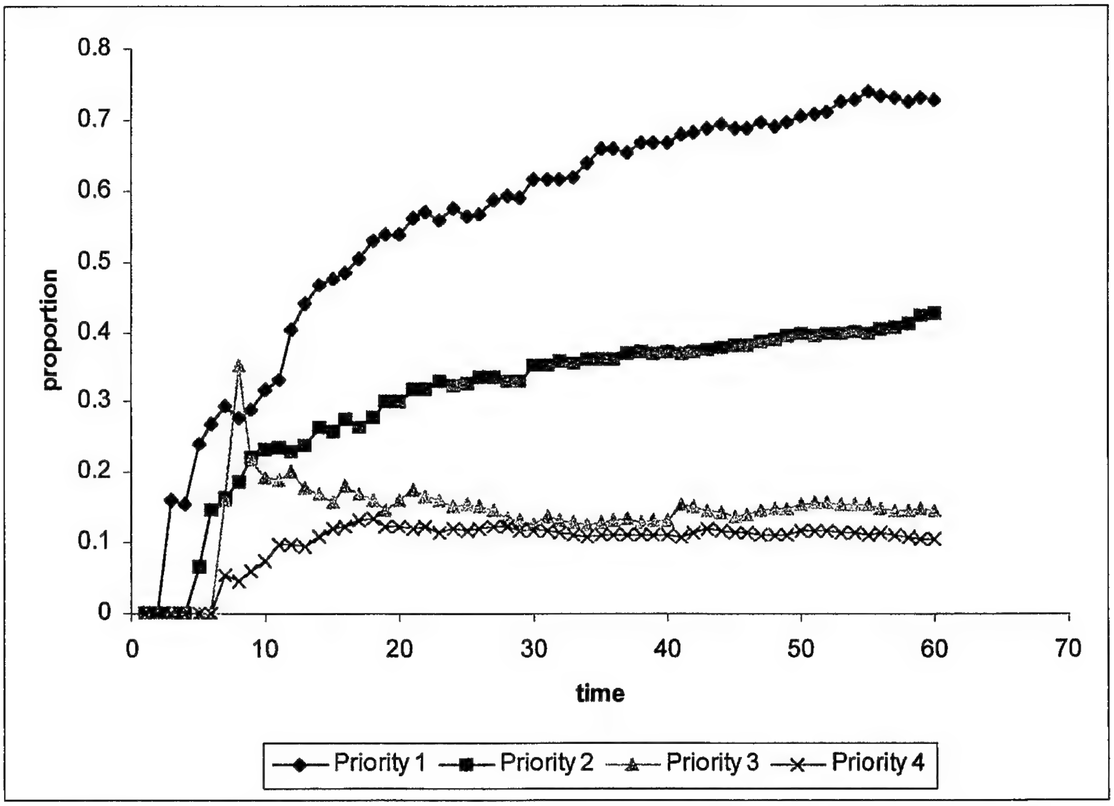

Figure 45. Cumulative Proportion of Good Messages to Number of Messages Generated by Priority.

4. Case 4 (HH)

The input parameters that were changed for Case 4 (HH) from Case 1 are channel capacity, anti-jam capability and the random number seeds for each run. The factors are now at (high, high) levels. The number of available channels on each satellite is increased from 8 to 16 (high); the anti-jam capability for each type was changed from 0.25 to 0.75 (high); and the random number seeds for runs 1 – 5 were: 75253171, 1964472944, 1202299975, 233217322, and 1911216000. All other input parameters remained the same as Case 1.

The average number of messages for all runs of Case 4 that were transmitted successfully, "stopG" and "stopNG" over time are shown in Figure 46. Table 12 shows the values for the number of good messages transmitted at 15 second increments. The

number of good messages transmitted has increased over 4 times from Case 1. The number of channels used for each satellite over time is shown at Figure 47. Similar graphs that show channel use by priority are included in Appendix C (Figures 92 – 96).

Figure 48 shows the average time to transmit a message for every good message transmitted by priority. Similar to Case 1, as time increases, the time to transmit depends upon the priority of the message. Because the size of the message is based on the type of the message, the results correlate to the input parameters. The time to transmit priority 1 and 4 messages increased from Case 1, and the time to transmit priority 2 and 3 messages decreased.

The proportion of good messages to the number of messages generated for each priority is shown in Figure 49. The proportion has increased from Case 1 for all priorities. Priority 4 messages did not increase as substantially as priority 1, 2 and 3 good messages. This is because maximum time expired before there was a channel available to transmit them (see Appendix B; Figure 75 did not change substantially compared to Figure 60).

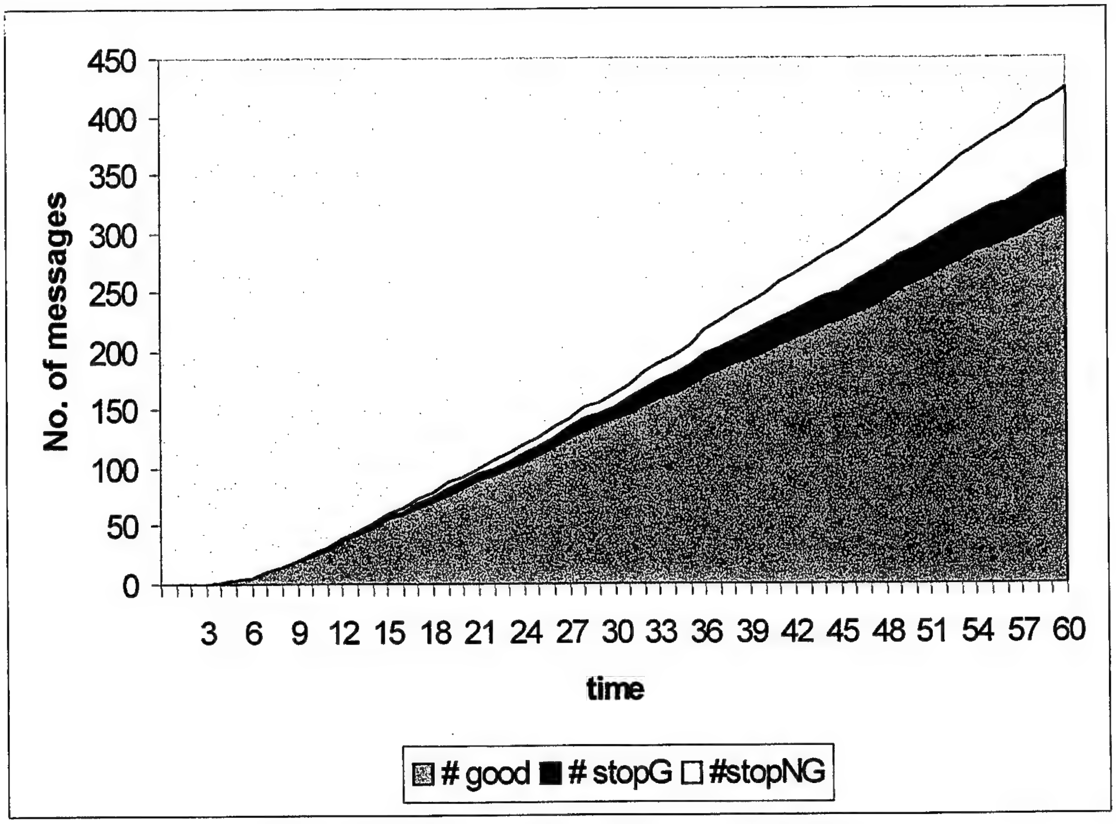

Figure 46. Case 4 (HH): Message Status Summary.

Time (seconds)	Number of Good Message Transmissions		Proportion Increase in Number of Good Transmissions in Case 4 Over Case 1
	Case 1	Case 4	
15	12.8	56.4	4.4
30	32.8	142.2	4.3
45	54.6	225.8	4.1
60	76.2	314.8	4.1

Table 12. Good Message Transmission Time Comparison for Cases 1 (LL) and 4 (HH).

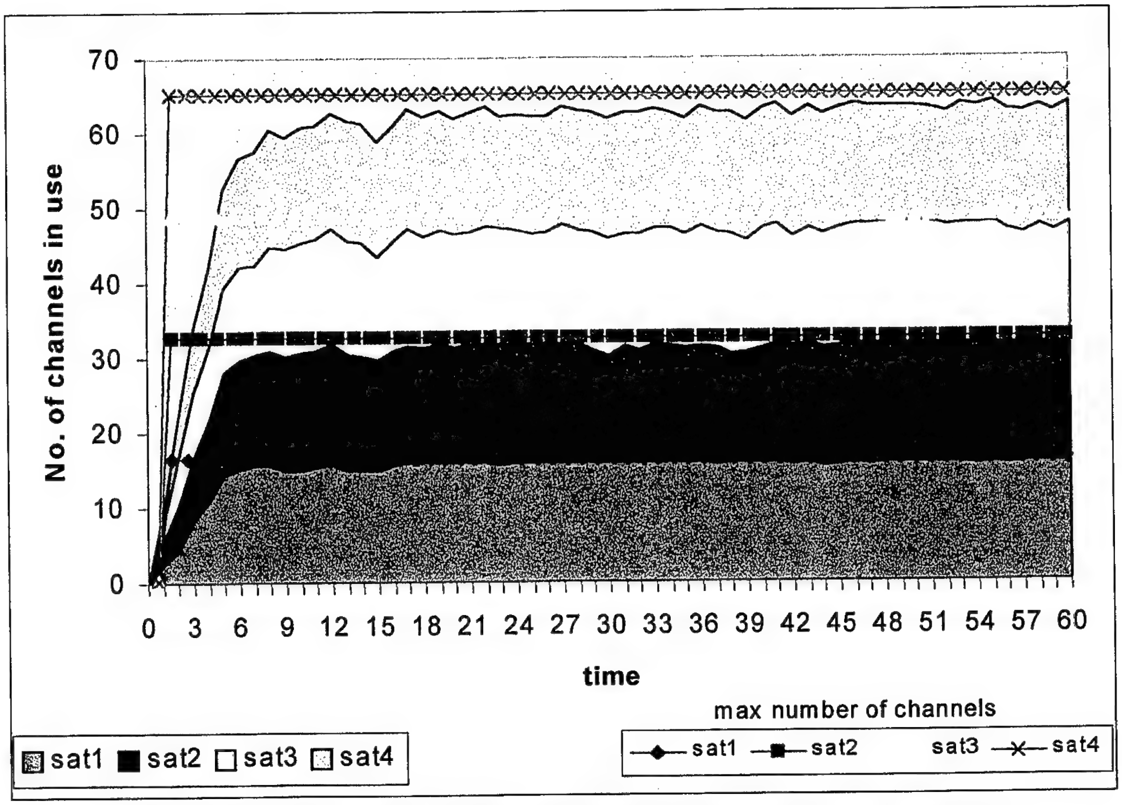

Figure 47. Case 4 (HH): Cumulative Number of Channels in Use Over Time.

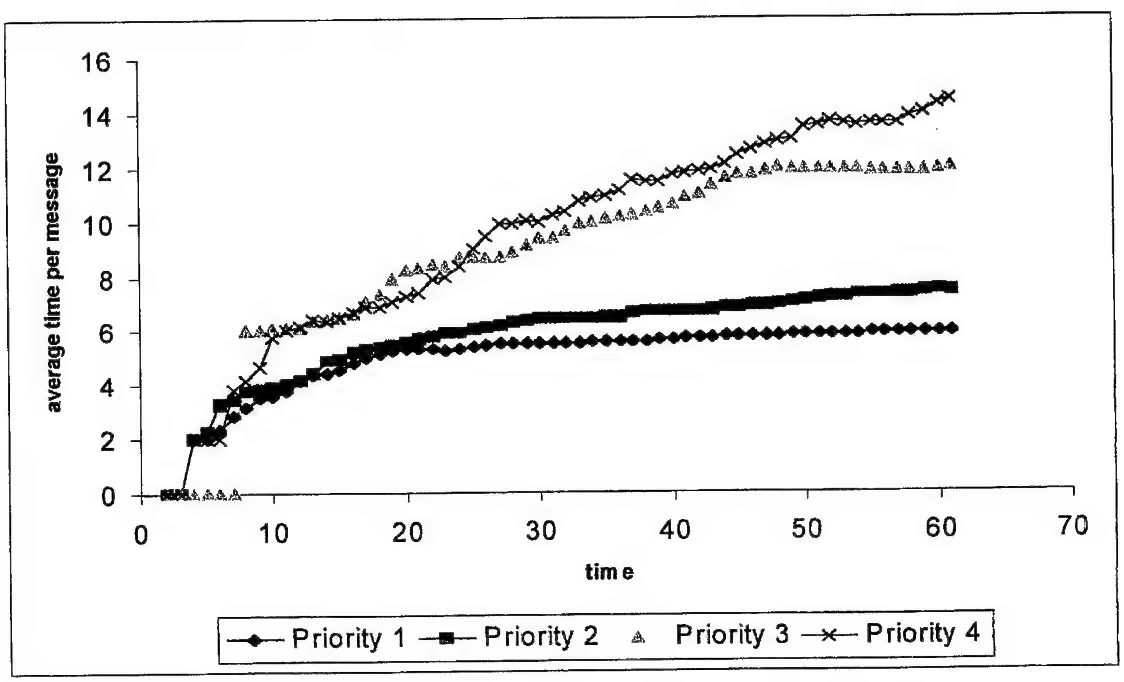

Figure 48. Case 4 (HH): Average Time to Transmit Good Messages.

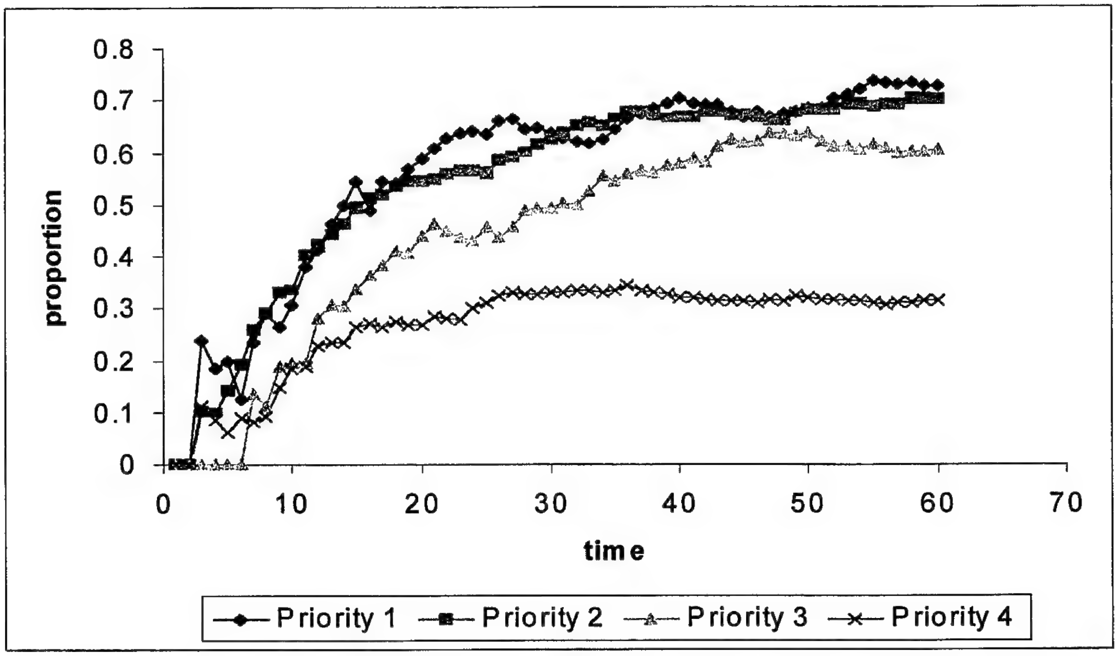

Figure 49. Proportion of Good Messages to Number of Messages Generated by Priority.

5. Summary

Summary statistics for each case and MOE were collected and are shown at Appendix E. Table 13 shows a summary for the total number of good transmissions for each case over 15 simulated second intervals. The number of good transmissions increase from Case 1 based upon the change of parameters.

Time (seconds)	Number of Good Messages Transmitted			
	Case 1 (LL)	Case 2 (HL)	Case 3 (LH)	Case 4 (HH)
15	12.8	17.4	33.2	56.4
30	32.8	54.2	84.2	142.2
45	54.6	89.8	136.2	225.8
60	76.2	125.2	190.4	314.8

Table 13. Total Number of Good Message Transmissions Over Time.

Table 14 shows a summary for the average time to transmit messages for each case by priority at time 60. The results do not show a significant difference between the different cases. The analysis of variance discussion in Section C considers whether there is a significant difference for the average time to transmit.

	Case 1 (LL)	Case 2 (HL)	Case 3 (LH)	Case 4 (HH)
Priority1	5.71	5.47	6.36	5.89
Priority 2	8.36	7.96	10.55	7.41
Priority 3	12.65	10.26	11.32	11.98
Priority 4	13.45	13.62	14.14	14.43
All messages	9.0	9.22	9.09	8.76

Table 14. Average time to transmit Messages by Priority, Time 60.

Table 15 shows a summary of the proportion of good messages to the number of messages generated for each case by priority at time 60. The proportion comparisons from Case 1 to the other three cases are similar to the results of those in Table 13.

	Case 1 (LL)	Case 2 (HL)	Case 3 (LH)	Case 4 (HH)
Priority1	0.19	0.26	0.72	0.73
Priority 2	0.18	0.24	0.42	0.70
Priority 3	0.17	0.22	0.14	0.60
Priority 4	0.06	0.20	0.10	0.31
All messages	0.14	0.23	0.35	0.57

Table 15. Proportion of Good Messages to Number of Messages Transmitted, Time 60.

C. ANALYSIS OF VARIANCE (ANOVA)

A two-way Analysis of Variance (ANOVA) was conducted for each MOE. The following model was used to represent this two-factor experiment:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijk}$$

where μ represents the expected value over all populations, α represents the anti-jam factor, β represents channel capacity factor, γ represents the interaction parameter between the two factors, and ε represents the random error term. Factor α has two levels, i = 1, 2 (for low and high anti-jam ability). Factor β has two levels, j = 1, 2 (for low and high number of channels); and k = 1, 2, 3, 4, and 5 observations [Ref. 16, p. 415].

Table 16 shows the ANOVA for the number of good transmissions for all messages ($\alpha = 0.05$). The "F" value is greater than "F statistic" value for both factors

indicating that there is a difference between the means for anti-jam capability and channel capacity. These results imply that the main effects of anti-jam capability and the channel capacity do affect the number of good messages transmitted. The "F" value for the interaction effect is greater than the "F statistic", which implies that there is also an interaction effect between the two factors. The presence of an interaction effect is also shown in Figure 56. Appendix F shows the remaining ANOVA results and the interaction plots for the MOEs for all messages (Table 18, Figures 103, 108, 113, 118, and 123) and each priority (Tables 19 – 22, Figures 104 – 107, 109 – 112, 114 – 117, 119 – 122, 124 – 127).

ANOVA results for the time to transmit for all messages indicate the anti-jam capability and channel capacity factors do not affect the time to transmit messages (Appendix F, Table 18 and Figure 123). The ANOVA results for number of "stopG" messages (Appendix F, Table 18) show that there is a difference between the means for both factors, but there is no interaction effect. The parallel lines in the "stopG" interaction plot (Appendix F, Figure 108) also shows the no interaction effect.

ANOVA					
Source of Variation	Df	SS	MS	F	Fcrit
J (Anti-Jam)	1	115368.1	115368.05	265.9169	4.494
C (Channel Capacity)	1	37584.45	37584.45	86.63006	4.494
JxC (Interaction)	1	7106.45	7106.45	16.37997	4.494
Error	16	6941.6	433.85		
Total	19	167000.6			

Table 16. ANOVA Good Transmissions (All messages).

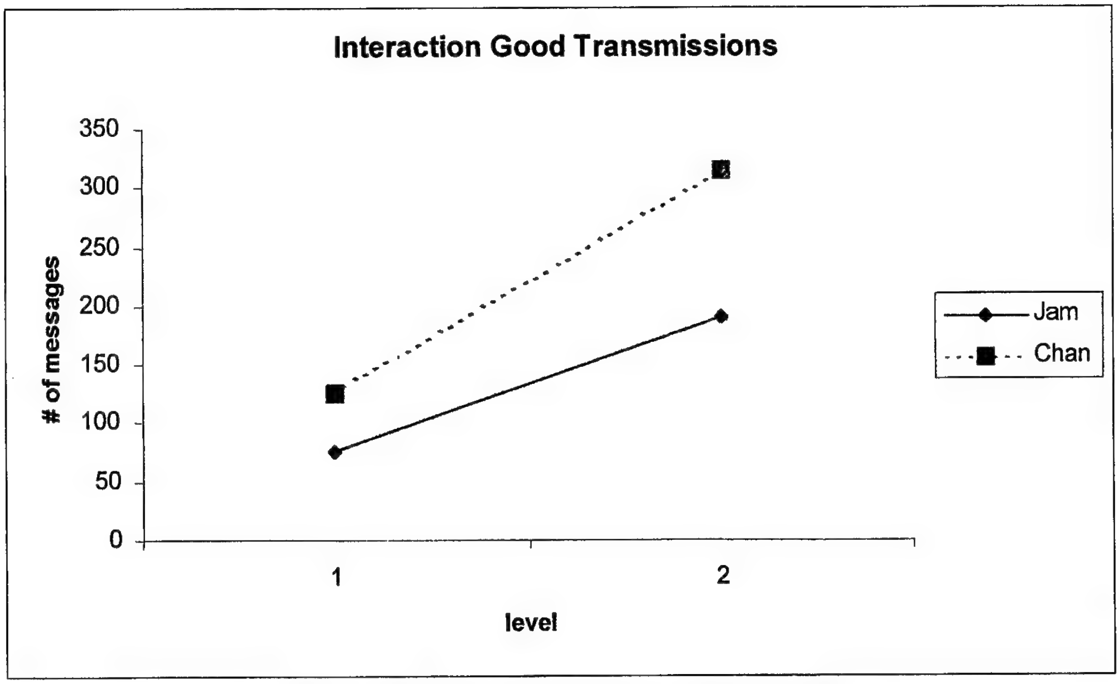

Figure 50. Good Transmissions (All messages).

The ANOVA results (Appendix F, Figure 113) for the "stopNG" messages indicate that there is a difference between the means for anti-jam capability and channel capacity, and there is an interaction effect. The ANOVA results (Appendix F, Figure 118) for the proportion of good messages to the number of messages generated for each priority indicate that there is a difference between the means and there is an interaction effect.

Table 17 displays a summary of the ANOVA results for each MOE for all messages.

The Analysis of Variance is a preliminary data analysis result for this model. The focus of this thesis is not to conduct data analysis using the model, but to describe and demonstrate the features of the model and how it can be used to answer specific questions.

MOE	Difference Between Means	Interaction Effect
Number of good transmissions	YES	YES
Number of "StopG" messages	YES	NO
Number of "StopNG" messages	YES	YES
Time to transmit messages	NO	NO
Number of good messages / number of total messages	YES	YES

Table 17. ANOVA Results Summary (For all messages).

VI. RECOMMENDATIONS

The methodology and model design presented in this thesis provide a useful model for answering questions about communications involving geosynchronous satellites. Many features of the model are useful for answering a variety of questions. However, there are some areas of the model where it would be beneficial to add additional features to provide further analysis capabilities.

The model is not dynamic in the area of satellite locations. It would be beneficial to modify the model in order for the user to input the location of the satellites and to designate specific areas of responsibility for each satellite. In building this modification, it would be useful to have satellites with different capabilities at specified locations (i.e., different data rates, ranging from low to high, modify the anti-jam capability for each satellite and have specified frequencies on each satellite).

It would also be advantageous to modify a portion of the input locations to a specific area of interest. This could be done with a slight modification of the current model (i.e., add a percentage that would set to a specified area of interest and the remainder to the upper and lower bounds for the input latitude and longitude).

A more sophisticated jamming process could also be added to the model. Different types of jammers with different capabilities would be a beneficial improvement. For example, a microwave radar can cause interference to communication. A simulated microwave radar could be a type of jammer with appropriate frequencies that it could jam. After adding more sophisticated jammers, it would be useful to allow the sender and receiver to select and change frequencies if a specific frequency is jammed.

Once these additions are made, the simulation could be added as a high resolution module to other models. To make this model compatable with another model, the input portion of the model would require modification. The jammers and the output portion of the model would also need to be tailored to the parent model.

Models that require near-earth or semi-synchronous satellites could be designed in a similar fashion. However, the location of the satellites would be dependent on the location of the satellite at the start of the simulation and the time in the model a particular action needs to take place. Specifications specific to the satellites such as sensor capabilities and their corresponding equations would need to be added.

Finally, JWARS would be able to utilize this model to investigate the satellite aggregation issue. With some modification, it could become the high resolution module for satellite representation in JWARS.

APPENDIX A. SIMSATCOM PROGRAM DESCRIPTION

This appendix discusses random number generation, flow chart model logic and a detailed description of each step. The flowcharts shown in Figures 51 – 56 describe the steps of the simulation. An extract of the Uniform Random Number Generator method follows. The method is converted from the Pascal Random Number Generator described in Law and Kelton. [Ref. 18, p. 451-454]

```
Zi = stream
Hi15 = Zi \ B2E16
Lowprd = (Zi - Hi15 * B2E16) * MULT1
Low15 = Lowprd \ B2E16
Hi31 = Hi15 * MULT1 + Low15
Ovflow = Hi31 \ B2E15
Zi = (((Lowprd - Low15 * B2E16) - MODLUS) + (Hi31 - Ovflow * B2E15) * B2E16) + Ovflow
If Zi < 0 Then Zi = Zi + MODLUS
Hi15 = Zi \ B2E16
Lowprd = (Zi - Hi15 * B2E16) * MULT2
Low15 = Lowprd \ B2E16
Hi31 = Hi15 * MULT2 + Low15
Ovflow = Hi31 \ B2E15
Zi = (((Lowprd - Low15 * B2E16) - MODLUS) + (Hi31 - Ovflow * B2E15) * B2E16) + Ovflow
If Zi < 0 Then Zi = Zi + MODLUS
stream = Zi
rndm = (2 * (Zi \ 256) + 1) / 16777216
```

The following subsections describe the steps of the simulation.

1. Reset

The "reset" procedure sets the sheets on the spreadsheet to the starting position. It also runs the procedures to set the number of satellites and the number of channels on each of the satellites. This updates the entire "sat chan" sheet with the information that was input by the user. "Reset" also runs the "setjammers" routine, which assigns random locations for each of the jammers. An extract of the "setjammers" procedure follows:

```
For numJam = 1 To maxNumJam
    UnifRand rndNum, stream
    Cells(rnum, latcol).Value = Int((upbndLat - lowbndLat + 1) * rndNum + lowbndLat)
    UnifRand rndNum, stream
```

```
        Cells(rnum, longCol).Value = Int((upbndLong - lowbndLong + 1) * rndNum +
            lowbndLong)
        UnifRand rndNum, stream
        Cells(rnum, maxrngcol).Value = Int((upbndRng - lowbndRng + 1) * rndNum +
            lowbndRng)
        rnum = rnum + 1
Next
```

If the user desires to employ fixed locations for the jammers, this procedure in the "reset" routine must be commented out and the locations manually entered on the "jammer" sheet prior to running the program.

2. Execute the New Message Process

Step 2 initiates the new message process at Step 12. After the execution of this procedure, continue with Step 3.

3. Number of Iterations

This is a counter for a "For" loop to run the model for the set number of time increments, with each increment being one second.

4. Increment Time

Once all new messages have been processed, time on the "sim" sheet advances using the "IncTime" procedure. This procedure increments the *cum time* cell on the "sim" sheet by one. A subprocedure, "IncTimeSatChan" is also run to advance time on the "sat chan" sheet. Finally, a subprocedure, "UpdateCumSat" is run to update the cumulative number of satellites being used on the "sat chan" sheet. This procedure adds the satellites in the *sat chan* column to the cumulative number of channels used and puts the new value in the *cum sat* column.

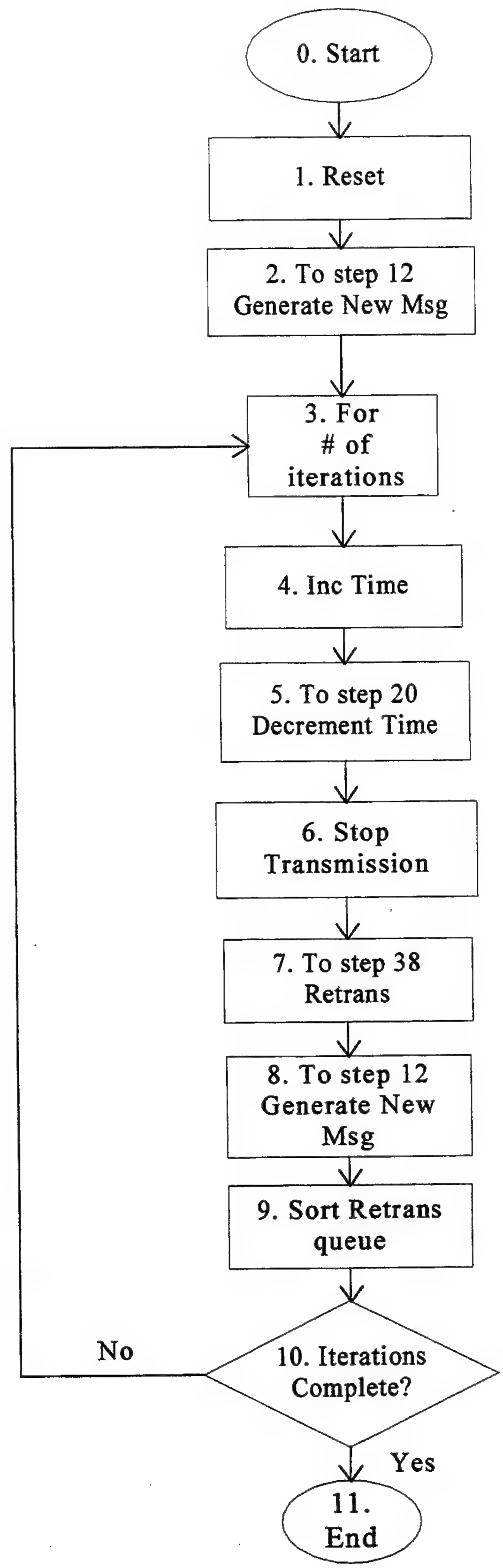

Figure 51. Main Program Flow Chart, Steps 1 – 11.

5. Execute the Decrement Time Process

Step 5 initiates the decrement time process at Step 21. After execution of this procedure continue with Step 6.

6. Stop Transmission

Step 6 determines whether the maximum time for each message in the retransmission queue has been reached. The procedure compares the *time to stop trying* column with the *current time*. If the times are equal, this procedure will stop the message process. The following is an extract from the procedure.

```
time = Sheets("sim").Cells(9, 2).Value
Sheets("Retrans").Select
maxRow = Cells(2, 2).Value
For chkRow = srow To maxRow
        If (time = Cells(chkRow, mxTmCol).Value) And (Cells(chkRow, stcol).Value = "w")
                        Then
                Cells(chkRow, stcol).Value = "stop"
                origMsgNum = Cells(chkRow, 2).Value
                MsgNumRow origMsgNum, origMsgRow, msgtime
                Sheets("sim").Select
                If Cells(origMsgRow, 34).Value = "s1" Then
                        Cells(origMsgRow, 34).Value = "stopG" 'this puts stop but msg good
                                in status col on "sim"
                        'indicates ack msg jammed
                        Sheets("Retrans").Cells(chkRow, stcol).Value = "stopG"
                Else
                        Cells(origMsgRow, 34).Value = "stopNG" 'puts stop msg never made
                                it
                        Sheets("Retrans").Cells(chkRow, stcol).Value = "stopNG"
                End If
                Sheets("Retrans").Select
        End If
Next
```

7. Execute the Retransmit Message Process

Step 7 initiates the retransmit message process at Step 38. After execution of this procedure, continue with Step 8.

8. Execute the New Message Process

Step 8 invokes the new message process at Step 12. After the execution of this process, continue with Step 9.

9. Sort

Step 9 sorts the retransmission queue by the priority (type) of the message and then by time. This is done to ensure that the higher priority messages get retransmitted first. The following is an extract of this procedure.

```
Sheets("Retrans").Select
startrow = 7
sortrow = Cells(2, 2).Value
If sortrow < 100 Then
        Range("A7:V107").Select
        Selection.sort Key1:=Range("C7"), Order1:=xlAscending, Key2:=Range _
        ("A7"), Order2:=xlAscending, Key3:=Range("B7"), Order3:= _
        xlAscending, Header:=xlGuess, OrderCustom:=1, MatchCase:=False _
        , Orientation:=xlTopToBottom
ElseIf sortrow < 200 Then
        Range("A7:V207").Select
        Selection.sort Key1:=Range("C7"), Order1:=xlAscending, Key2:=Range _
        ("A7"), Order2:=xlAscending, Key3:=Range("B7"), Order3:= _
        xlAscending, Header:=xlGuess, OrderCustom:=1, MatchCase:=False _
        , Orientation:=xlTopToBottom
ElseIf sortrow < 300 Then
        Range("A7:V307").Select
```

10. Next Iteration

Step 10 checks to see if there is another time step increment. If there is, go to Step 3; otherwise, continue to Step 11.

11. End

This step ends the program.

12. New Message Process

Step 12 begins the new message process. The first procedure inside this process is the new message generation procedure, "Msg_Input_Lat_Long_Type". This procedure generates new messages for the current time step.

13. Number of Message Types

Step 13 starts the "For" loop that occurs for each message type in the generate new message procedure.

14. Generate Number of Messages in Message Type

For each message type a Poisson random number is generated to determine the number of messages that will occur during that time step. The Poisson random number generator uses the lambda values that were input by the user. These lambda values are the average rate of occurrence for the message type. The following is an extract of the Poisson random number generator procedure:

```
theNum = 0
a = Exp(-lambda)
b = 1
Do Until Done
        UnifRand UnifRnd, stream
        b = b * UnifRnd
        If b < a Then
                Done = True
        Else
                theNum = theNum + 1
        End If
Loop
rndNum = theNum
```

15. Number of Messages for each Message Type

A "For" loop is executed for each message of every message type.

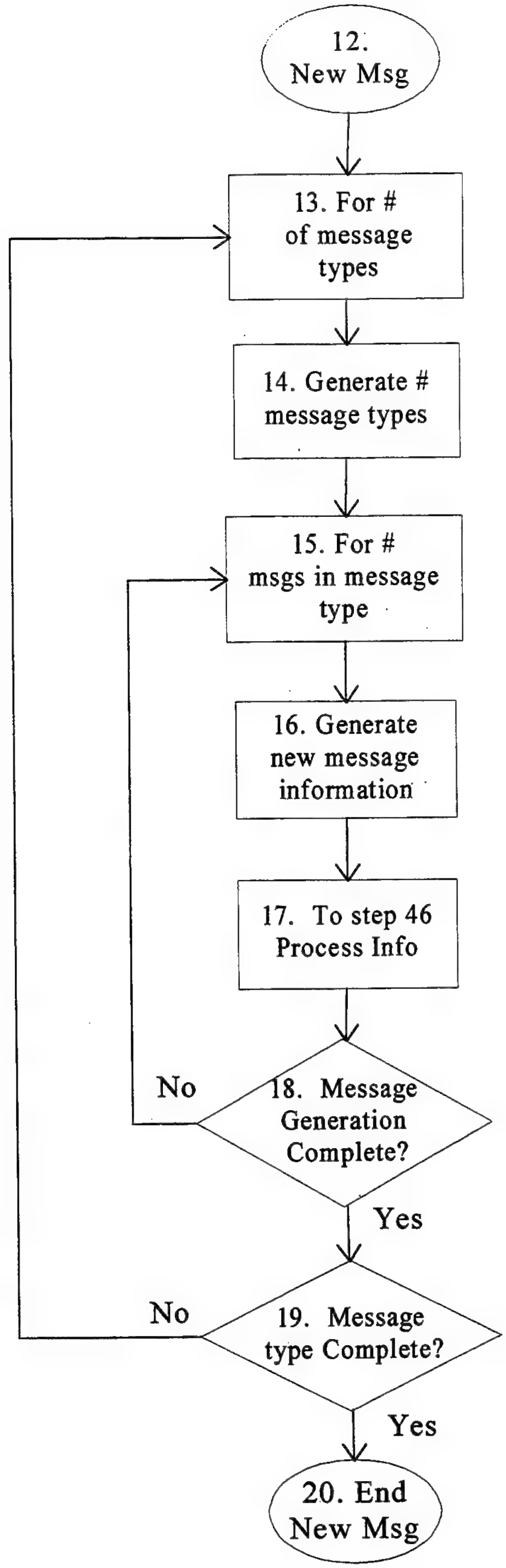

Figure 52. New Message Flow Chart, Steps 12 – 20.

16. Generate New Message Information

Several Uniform random numbers are generated to create the following data for the new message:

- a new location for the sender and receiver; the sender and receiver type, which indicates the type of equipment the sender and receiver use to counteract jamming;
- the number of bits, which corresponds to the appropriate type of message;
- to determine if the message is transmitted using the low or medium data rate if the message is transmitted using satellites "3" or "4".

The following is an extract of the new message generation procedure.

```
Cells(rnum, tmcol).Value = Cells(9, 2).Value
NewMsg rnum
Cells(rnum, mtcol).Value = msgType
UnifRand rndNum, stream
Cells(rnum, latcol).Value = Int((upboundLat - lowboundLat + 1) * rndNum +
        lowboundLat)
UnifRand rndNum, stream
Cells(rnum, latcol + 1).Value = Int((upbndLong - lowbndLong + 1) * rndNum +
        lowbndLong)
UnifRand rndNum, stream
Cells(rnum, latcol + 2).Value = Int((upboundLat - lowboundLat + 1) * rndNum +
        lowboundLat)
UnifRand rndNum, stream
Cells(rnum, latcol + 3).Value = Int((upbndLong - lowbndLong + 1) * rndNum +
        lowbndLong)
UnifRand rndNum, stream
Cells(rnum, tcol).Value = Int((upbndStype - lowbndStype + 1) * rndNum +
        lowbndStype)
UnifRand rndNum, stream
Cells(rnum, tcol + 1).Value = Int((upbndRtype - lowbndRtype + 1) * rndNum +
        lowbndRtype)
Cells(rnum, tcol + 2).Value = msgType 'priority is same as msgtype for now
UnifRand rndNum, stream
Cells(rnum, mcol + 2).Value = Int((upbits - lowbits + 1) * rndNum + lowbits)
UnifRand rndNum, stream
Cells(rnum, 12).Value = rndNum  'puts random # in "sim" active row rand # col (12)
ack = False 'indicates this is not an auto acknowledgment message
```

17. Execute Process Information

Step 17 initiates the "process info" procedure at Step 46, the final operation for processing messages. After execution of this process, continue with Step 18.

18. Next Message

Step 18 iterates to the next message for the specified message type from Step 15. Once the required number of messages for the designated message type have been processed, go to Step 19.

19. Next Message Type

Step 19 returns the program to Step 13 if there is another message type to process, otherwise continue with Step 20.

20. End New Message

Step 20 ends the generate new message process. Program control is returned to either Step 2 or Step 8.

21. Decrement Time

Step 21 begins the Decrement Time process which decrements time on the "time" sheet. This is done to monitor the time remaining to transmit a message. The following is an excerpt from the "DecrTime" procedure, which encompasses Steps 21 - 37.

```
For satNum = 1 To maxSat
        For chan = 1 To maxChan
                If Cells(crow, tmcol).Value <> "" Then
                        timeLeft = Cells(crow, tmcol).Value
                        If timeLeft - 1 <= 0 And (Cells(crow, 7 + (satNum - 1) * 4) <>
                                curTime) Then
        'clears the contents of the channel that has completed its transmission
        'a blank row means it is free to transmit
```

```
'the 2nd part ensures that an ack msg added does not decr time in this time step
                              msgNum = Cells(crow, mcol * satNum).Value
                              MsgNumRow msgNum, MsgRow, msgtime
                              DecCumSat satNum
                              UpdateCumSat prevRow
                              Sheets("time").Select
                              Set r1 = Range(Cells(crow, 4 + (satNum - 1) * 4), Cells(crow,
                                    5 + (satNum - 1) * 4))
                              Set r2 = Range(Cells(crow, 6 + (satNum - 1) * 4), Cells(crow,
                                    7 + (satNum - 1) * 4))
                              Set theRng = Union(r1, r2)
                              theRng.Select
                              Selection.ClearContents
                              Sheets("sim").Select
                              If Cells(MsgRow, upCol).Value = satNum Then
                                    MsgSent msgNum, curRow, stream
                              End If
                              Sheets("time").Select
                        Else
                              Cells(crow, tmcol).Value = timeLeft - 1
                        End If
                  End If
                  crow = crow + 1
            Next
            crow = init
            tmcol = tmcol + 4
      Next
```

22. Decrement Time for all Satellites

Step 22 starts the "For" loop that decrements time for each satellite.

23. Decrement Time for all Channels

Step 23 starts the inner "For" loop of the "DecrTime" procedure. This "For" loop occurs for every channel on the current satellite.

24. Channel Used

If the current channel is transmitting a message, continue with Step 25; otherwise, go to Step 35.

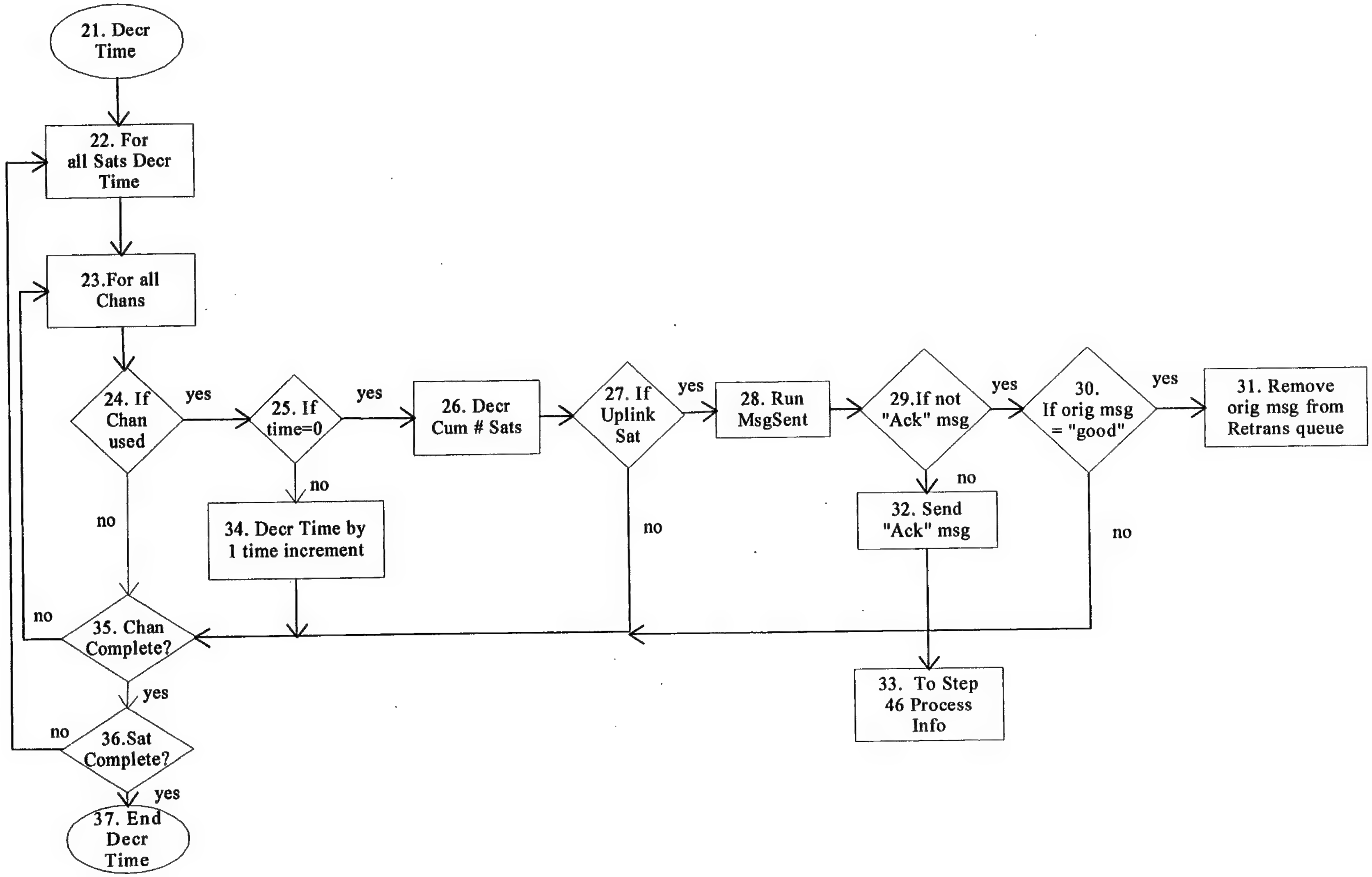

Figure 53. Decrement Time Flow Chart, Steps 21 – 37.

25. Time Up

If time = 0 on the "time" sheet, continue with Step 26; otherwise, go to Step 34. This initiates the process of ending the transmission of the message and begins the transmission of an acknowledgment message if one is necessary.

26. Decrement Cumulative Number of Satellites

Step 26 decrements the number of users on the satellite channel ("sat chan" sheet) by the procedure "DecCumSat". The following is an extract of this procedure.

```
Sheets("sat chan").Select
Done = False
tmcol = 1
num = 1
cnum = 2
curRow = Cells(9, 2).Value
Do Until Done
        If num = SatNumToDec Then
                dec = Cells(curRow, cnum + (num - 1) * 2).Value
                Cells(curRow, cnum + (num - 1) * 2).Value=dec - 1
                Done = True
        Else
                num = num + 1
        End If
Loop
```

After execution of this procedure, the message is also removed from the "time" sheet as indicated in the extract of the "DecrTime" procedure in Step 21.

27. If Uplink Satellite

If the current channel is on the uplink satellite, continue with Step 28; otherwise, go to Step 35. This is to ensure that Steps 28 - 33 are executed only for the uplink portion of the transmission.

28. Message Sent

The procedure, "MsgSent" initiates the process to annotate that a message has been sent. The following excerpt from this procedure includes Steps 29 - 33.

```
If Cells(MsgRow, AckCol).Value <> "ack" Then If Cells(MsgRow, AckCol).Value <> "ack"
        Then
    SendAck MsgRow, curRow, stream
    GoodMsgNum msgNum, goodMsgRow, status
    Sheets("sim").Select
    Cells(curRow, 1).Value = time
    If status = "good" Then
        Cells(MsgRow, cnum).Value = "s1" 'indicates msg went thru "good" need to
            wait to see if ack does
    Else
        Cells(MsgRow, cnum).Value = "s3" 'indicates msg was partially jammed
    End If
Else
    Cells(MsgRow, cnum).Value = "s2"    'indicates ack went thru
    origMsgNum = msgNum * (-1)
    MsgNumRow origMsgNum, origMsgRow, msgtime
    GoodMsgNum origMsgNum, goodMsgRow, status
    If status = "good" Then
        'this will take the original message of the Retrans queue
        'otherwise the msg will stay on the retrans queue to be retransmitted
        'which is what should happen if the message was jammed at all
        Sheets("sim").Cells(origMsgRow, cnum).Value = "s"
        TakeOffRetrans origMsgNum
    End If
End If
```

29. Acknowledgment Message

If the message is an acknowledgment message, Step 29 sends control to Steps 30 – 31; otherwise, go to Steps 32 – 33.

30. Original Message "good"

If the original message was transmitted "good", continue with Step 31; otherwise, go to Step 35.

31. Remove Message

Step 31 removes the message from the retransmission queue. The following excerpt is from the "TakeOffRetrans" procedure:

```
Sheets("Retrans").Select
Do Until Done
If msgNum = Cells(rnum, mcol).Value Then
        Cells(rnum, stcol).Value = "good"
        Done = True
Else
        rnum = rnum + 1
End If
Loop
```

32. Send Acknowledgment

If the message was not an acknowledgment message, then execute the "SendAck" procedure. This procedure copies the information from the "time" sheet to the "sim" sheet, but the original sender is now the receiver and the receiver is now the sender. The acknowledgment message indicates whether the original message was a "good" message or a partially jammed, "pj" message. The following is an excerpt from the "SendAck" procedure.

```
priority = 4
AckBits = 2000  'set num of bits to transmit acknowledgment
Sheets("sim").Select
Cells(curRow, 1).Value = Cells(9, 2).Value
mtyp = Cells(MsgRow, 3).Value
slat = Cells(MsgRow, 5).Value
slon = Cells(MsgRow, 6).Value
rlat = Cells(MsgRow, 7).Value
rlon = Cells(MsgRow, 8).Value
styp = Cells(MsgRow, 9).Value
rtyp = Cells(MsgRow, 10).Value
RandNum = Cells(MsgRow, 12).Value
jtyp = Cells(MsgRow, 27).Value  'indicates if original msg was "g" or"pj"
Cells(curRow, 3).Value = mtyp
Cells(curRow, 5).Value = rlat
Cells(curRow, 6).Value = rlon
Cells(curRow, 7).Value = slat
```

```
Cells(curRow, 8).Value = slon
Cells(curRow, 9).Value = rtyp
Cells(curRow, 10).Value = styp
Cells(curRow, 4).Value = AckBits
Cells(curRow, 11).Value = priority
Cells(curRow, 12).Value = RandNum
Cells(curRow, 28).Value = "ack"
Cells(curRow, 30).Value = jtyp
mnum = Cells(MsgRow, 2).Value
Cells(curRow, 2).Value = mnum * (-1)
ack = True
processInfo curRow, stream, mtyp, ack
NewRowSim curRow
```

33. Execute Process Information

Step 33 initiates the "process info" procedure, the final operation for processing messages, at Step 46. After execution of Steps 46 – 63, continue with Step 34.

34. Decrement Time

This step decrements the time by one time unit if the current message on the "time" sheet is still transmitting.

35. Next Channel

If there is another channel on the current satellite, go to Step 23; otherwise, go to Step 36.

36. Next Satellite

If there is another satellite to be processed, return to Step 22; otherwise, go to Step 37.

37. End Decrement Time

Step 37 ends the Decrement Time process and control is returned to Step 5.

38. Retransmit Message Process

Step 38 initiates the Retransmit Message process. This process retransmits messages that are in the retransmission queue.

39. Check for Retransmission

Step 39 begins the "RetransMsg" procedure with a "Do" loop for retransmitting messages. This "Do" loop occurs for all messages in the retransmission queue. The following is an excerpt from this procedure.

```
Sheets("sim").Select
time = Cells(curRow, tmsim).Value
Done = False
Sheets("Retrans").Select
Do Until Done
        retranstime = Cells(crow, tmcol).Value
        If (Cells(crow, tmcol).Value = time And Cells(crow, stcol).Value = "w") Or (Cells(crow,
                tmcol).Value < time And Cells(crow, stcol).Value = "w") Then
                        'the second part of the if statement indicates that there weren't
                                available channels previously
                AvailChan AvailCh, crow, "Retrans"
                If AvailCh Then
                        sendRetrans crow, curRow, msgType
                        processInfo curRow, stream, msgType, ack
                        Sheets("sim").Select
                        If Cells(curRow, 34).Value = "w" Then
                                Sheets("Retrans").Select
                                Cells(crow, 14).Value = "w"
                        ElseIf Cells(curRow, 34).Value = "t" Then
                                Sheets("Retrans").Select
                                Cells(crow, 14).Value = "t"
                        End If
                        NewRow curRow
                        crow = crow + 1
                Else
                        crow = crow + 1
                End If
        ElseIf Cells(crow, tmcol).Value = "" Then
                Done = True
        Else
                crow = crow + 1
        End If
        Sheets("Retrans").Select
Loop
```

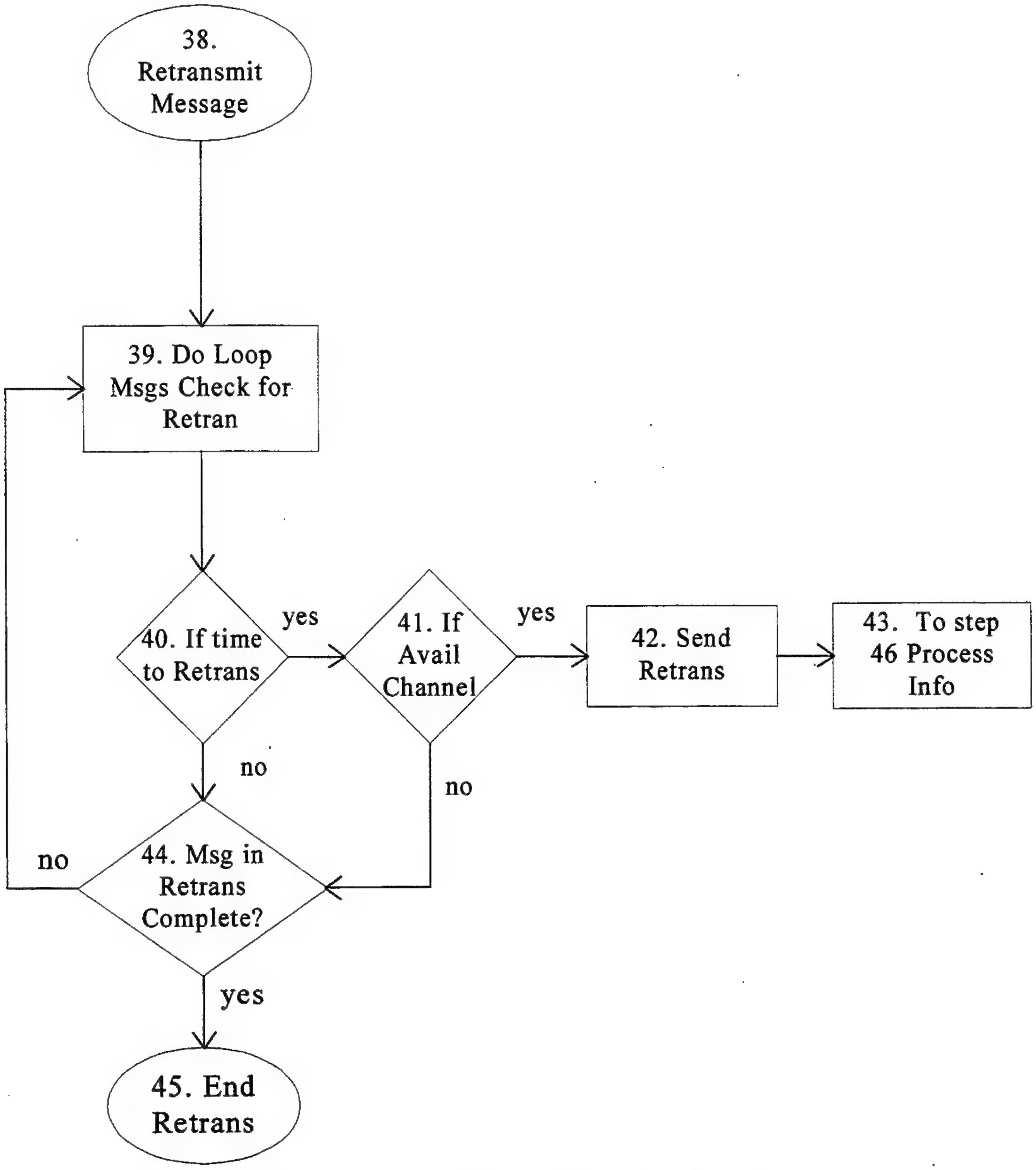

Figure 54. Retransmit Message Flow Chart, Steps 38 – 46.

40. Time to Retransmit

If the time in the *time to transmit* column is less than or equal to the *current time*, and the *status* column in the "Retrans" sheet indicates waiting, "w", continue with Steps 41 to 43; otherwise, go to Step 44.

41. Available Channel

If there is an available channel for both the uplink and the downlink on the current message, continue with Steps 42 and 43. Otherwise, if there is not an available channel, go to Step 44. The following is an extract of the "AvailChan" procedure.

```
If sheetnm = "sim" Then
        cnumUp = 14
ElseIf sheetnm = "Retrans" Then
        cnumUp = 16
End If
cnumDown = 17
Sheets(sheetnm).Select
satNumUp = Cells(curRow, cnumUp).Value 'identifies the current sat uplink
satNumDown = Cells(curRow, cnumDown).Value
Sheets("sat chan").Select
satChRow = Cells(9, 2).Value
satMax = Cells(6, 3).Value
Do Until Done
        If Cells(ChRow, cnum).Value = satNumUp Then
                satMaxCh = Cells(satRow, cnum).Value
                If Cells(satChRow, cnum).Value < satMaxCh Then
                        AvailCh = True
                        Done = True
                Else
                        AvailCh = False
                        Done = True
                End If
        Else
                cnum = cnum + 2
        End If
Loop
If satNumUp <> satNumDown And AvailCh = True Then
        Done = False
        cnum = 3
        Do Until Done
                If Cells(ChRow, cnum).Value = satNumDown Then
                        satMaxCh = Cells(satRow, cnum).Value
```

```
                    If Cells(satChRow, cnum).Value < satMaxCh Then
                        AvailCh = True
                        Done = True
                    Else
                        AvailCh = False
                        Done = True
                    End If
                Else
                    cnum = cnum + 2
                End If
        Loop
End If
```

42. Send Retransmission

Step 42 attempts to resend the message by calling the "SendRetrans" procedure. Information from the retransmission queue is copied into the "sim" sheet. The following is an extract from the procedure.

```
Sheets("Retrans").Select
Set r1 = Range(Cells(RetRow, 2), Cells(RetRow, 3))
Set r2 = Range(Cells(RetRow, 4), Cells(RetRow, 5))
Set r3 = Range(Cells(RetRow, 6), Cells(RetRow, 7))
Set r4 = Range(Cells(RetRow, 8), Cells(RetRow, 9))
Set r5 = Range(Cells(RetRow, 10), Cells(RetRow, 11))
Set retRng = Union(r1, r2, r3, r4, r5)
retRng.Select
Selection.copy
Sheets("sim").Select
Set sr1 = Range(Cells(curRow, 2), Cells(curRow, 3))
Set sr2 = Range(Cells(curRow, 4), Cells(curRow, 5))
Set sr3 = Range(Cells(curRow, 6), Cells(curRow, 7))
Set sr4 = Range(Cells(curRow, 8), Cells(curRow, 9))
Set sr5 = Range(Cells(curRow, 10), Cells(curRow, 11))
Set simRng = Union(sr1, sr2, sr3, sr4, sr5)
simRng.Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
SkipBlanks:=False, Transpose:=False
time = Cells(9, 2).Value
Sheets("Retrans").Select
RandNum = Cells(RetRow, 18).Value
Sheets("sim").Select
Cells(curRow, 12).Value = RandNum
Sheets("Retrans").Select
Cells(RetRow, 14).Value = "r"
Sheets("sim").Select
Cells(curRow, 29).Value = "r"
```

```
Cells(curRow, 1).Value = time
mtype = Cells(curRow, 3).Value 'msg type; value needed for processing info
```

43. Execute Process Information

Step 43 initiates the "process info" procedure, the final operation for processing messages, at Step 46. After execution of Steps 46 – 63 continue with Step 44.

44. Loop

Step 44 determines if there is another message in the retransmission queue. If there is another message in the queue, go to Step 39; otherwise, continue to Step 45.

45. End Retransmission

Step 45 ends the retransmission procedure and control is returned to Step 7.

46. Process Information

Step 46 begins the Process Information procedure.

47. Satellite Type

Step 47 identifies the satellites that will transmit the messages. The procedure compares the location of the sender and receiver to the appropriate satellite that will transmit the message. The following is an extract from the satellite type procedure.

```
maxSat = Sheets("sat chan").Cells(2, 4).Value
Sheets("sim").Select
If ((Cells(curRow, cstrt).Value >= 0 And Cells(curRow, cstrt).Value < 90) Or Cells(curRow,
            cstrt).Value = 360) Then
      If Sheets("sat chan").Cells(rstat, cstat).Value = True Then
            Sheets("sim").Cells(curRow, satUp).Value = 1
      ElseIf maxSat > 4 Then
            If Sheets("sat chan").Cells(rstat, cstat + 8).Value = True Then
                  Sheets("sim").Cells(curRow, satUp).Value = 5
            End If
      Else
            Sheets("sim").Cells(curRow, satUp).Value = 1
      End If
```

```
ElseIf (Cells(curRow, cstrt).Value >= 90 And Cells(curRow, cstrt).Value < 180) Then
        If Sheets("sat chan").Cells(rstat, cstat + 2).Value = True Then
                Sheets("sim").Cells(curRow, satUp).Value = 2
        ElseIf maxSat > 5 Then
                If Sheets("sat chan").Cells(rstat, cstat + 10).Value = True Then
                        Sheets("sim").Cells(curRow, satUp).Value = 6
                End If
        Else
                Sheets("sim").Cells(curRow, satUp).Value = 2
        End If
ElseIf (Cells(curRow, cstrt).Value >= 180 And Cells(curRow, cstrt).Value < 270) Then
        If Sheets("sat chan").Cells(rstat, cstat + 4).Value = True Then
                Sheets("sim").Cells(curRow, satUp).Value = 3
        ElseIf maxSat > 6 Then
                If Sheets("sat chan").Cells(rstat, cstat + 12).Value = True Then
                        Sheets("sim").Cells(curRow, satUp).Value = 7
                End If
        Else
                Sheets("sim").Cells(curRow, satUp).Value = 3
        End If
ElseIf (Cells(curRow, cstrt).Value >= 270 And Cells(curRow, cstrt).Value < 360) Then
        If Sheets("sat chan").Cells(rstat, cstat + 6).Value = True Then
                Sheets("sim").Cells(curRow, satUp).Value = 4
        ElseIf maxSat > 7 Then
                If Sheets("sat chan").Cells(rstat, cstat + 14).Value = True Then
                        Sheets("sim").Cells(curRow, satUp).Value = 8
                End If
        Else
                Sheets("sim").Cells(curRow, satUp).Value = 4
        End If
End If
If ((Cells(curRow, cstp).Value >= 0 And Cells(curRow, cstp).Value < 90) Or  Cells(curRow,
                cstp).Value = 360) Then
        If Sheets("sat chan").Cells(rstat, cstat).Value = True Then
                Sheets("sim").Cells(curRow, satDown).Value = 1
        ElseIf maxSat > 4 Then
                If Sheets("sat chan").Cells(rstat, cstat + 8).Value = True Then
                        Sheets("sim").Cells(curRow, satDown).Value = 5
                End If
        Else
                Sheets("sim").Cells(curRow, satDown).Value = 1
        End If
```

48. Copy Information

This step copies the equation information from the previous row to the current row. The columns copied are *data rate*, *uplink* and *crosslink* (if applicable), *transmission rate*, and *time to transmit*.

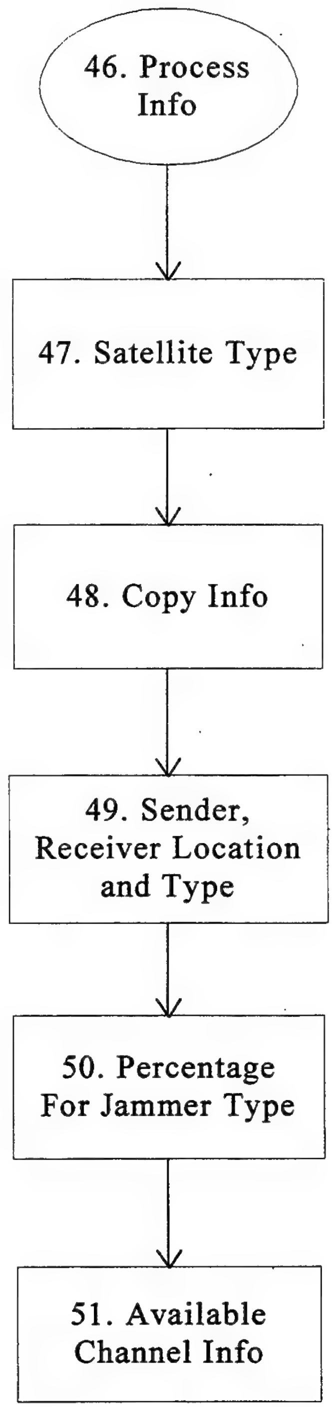

Figure 55. Process Information Flow Chart, Steps 47 – 51.

49. Location and Type

Step 49 inputs the sender and receiver location and type of user from the "sim" sheet to the "type" and "jammer" sheets.

50. Percentage Jammed

The procedure "perc" is implemented in Step 50. This procedure inputs the anti-jam capability proportion into the "jammer" sheet. The procedure goes to the "type" sheet and matches the type of user to the anti-jamming capability and records this information on the "jammer" sheet. The "jammer" sheet, previously discussed, provides additional information on how this value is used. The following is an extract from this procedure.

```
ctypenum = 9
Sheets("sim").Select
satJamType = Cells(curRow, ctypenum).Value
Sheets("type").Select
rtypeup = 3     'row for type sender from "type" sheet
rtypedown = 5   'row for type receiver from "type"
ctypeinit = 4
Rtype = 9       'first row to compare type #
ctype = 1       'col # to compare type #
cper = 2        'percentage col to return % value
jrow = 9        'from "jammer" sheet jam row
jcolup = 7      'from "jammer" sheet jam col for up
jcoldown = 16   'from "jammer" sheet jam col from down
Done = False
Do Until Done
        If Cells(Rtype, ctype).Value = Cells(rtypeup, ctypeinit).Value Then
                theperc = 1- Cells(Rtype, cper).Value
                Sheets("jammer").Select
                Cells(jrow, jcolup).Value = theperc
                UnifRand rndNum, stream
                Cells(jrow, 12).Value = rndNum  'puts random # in "jammer" rand # col
                Done = True
        Else
                Rtype = Rtype + 1
        End If
Loop
Sheets("type").Select
If Cells(rtypeup, ctypeinit).Value = Cells(rtypedown, ctypeinit).Value Then
        Sheets("jammer").Select
        Cells(jrow, jcoldown).Value = Cells(jrow, jcolup).Value
```

```
Else
        Done = False
        Rtype = 9
        Do Until Done
                If Cells(Rtype, ctype).Value = Cells(rtypedown, ctypeinit).Value Then
                        theperc = 1- Cells(Rtype, cper).Value
                        Sheets("jammer").Select
                        Cells(jrow, jcoldown).Value = theperc
                        UnifRand rndNum, stream
                        Cells(jrow, 21).Value = rndNum  'puts random # in "jammer" rand #
                                col
                        Done = True
                Else
                        Rtype = Rtype + 1
                End If
        Loop
End If
```

51. Available Channel

This step determines whether there is an available channel on the satellite(s) for both the uplink and downlink (if necessary). It selects the available channel number from the "time" sheet and returns the channel number, the row for the channel number, and the column number for the available satellite. It utilizes this channel next on the satellite that is transmitting. The following is an extract from this procedure.

```
Sheets("time").Select
Do Until SatDone
        If satUp = Cells(satRow, cnum).Value Then
                Done = False
                Do Until Done
                        If Cells(crow, cnum).Value = "" Then
                                ChNumUp = Cells(crow, ChCol).Value
                                RChNumUp = crow
                                ColChUp = cnum
                                Done = True
                        Else
                                crow = crow + 1
                        End If
                Loop
                SatDone = True
        Else
                cnum = cnum + 4
        End If
Loop
```

```
If satUp <> satDown Then
        SatDone = False
        cnum = 4
        crow = 12
        TimeCol = 5
        Do Until SatDone
                If satDown = Cells(satRow, cnum).Value Then
                        Done = False
                        Do Until Done
                                If Cells(crow, cnum).Value = "" Then
                                        ChNumDown = Cells(crow, ChCol).Value
                                        RChNumDown = crow
                                        ColChDown = cnum
                                        Done = True
                                Else
                                        crow = crow + 1
                                End If
                        Loop
                        SatDone = True
                Else
                        cnum = cnum + 4
                End If
        Loop
Else
        ChNumDown = ChNumUp
        RChNumDown = RChNumUp
        ColChDown = ColChUp
End If
```

52. Check Available Channel

If there is an available channel, go to Step 53; otherwise, go to Step 56. Step 41 provides an extract of the "AvailChan" procedure.

53. Communication Occurred

Step 53 calls the "CommOccur" procedure. This procedure determines whether the transmission was "good", meaning that no jamming occurred; "pj" indicating that the message was partially jammed; or "j" indicating that the message was completely jammed. The following is an excerpt from this procedure.

```
Sheets("jammer").Select
If Cells(crow, ccoldown).Value = 2 Then '2 indicates jam capability was 100%
        JamTotal curRow, msgType, ack
ElseIf Cells(crow, ccoldown).Value = 1 Then    '1 indicates jam cap was partial
```

```
		JamPartial curRow, msgType, ack
	Else
		JamNone curRow, msgType, ack
	End If
```

54. Check for Jam Total

Step 54 checks to see if the message was totally jammed. If it was, continue with Step 55; otherwise, go to Step 59.

55. Jam Total

Step 55 puts a "j" on the "sim" sheet to indicate that the message was completely jammed. The following is an extract from the "JamTotal" procedure.

```
Sheets("sim").Select
Cells(curRow, jcol).Value = "j" 'puts on "sim" sheet what jamming occurred to msg; value will
	never change
Cells(curRow, ccol).Value = "j" 'indicates the satellite is jammed
timLastTry = Cells(curRow, 1).Value
If (Not ack) Then
	WaitTimePri waitTime, msgType, maxWaitTime
	NeedToRetrans waitTime, curRow, maxWaitTime, timLastTry 'puts message in
		retransmission queue wait
End If
```

56. Wait Time by Priority

Step 56 calls the procedure "WaitTimePri" to determine the amount of time the message should wait before trying to retransmit. The amount of time is determined by the type of message. This procedure goes to the "type" sheet and matches the *message type* value to the *wait time* and *maximum wait time* values. The *wait time* value is the amount of time the sender will wait for an acknowledgment message before trying to send the message again. The *maximum wait time* value is the maximum amount of time the sender is willing to continue trying the message without receiving an acknowledgment message. The following is an extract of this procedure.

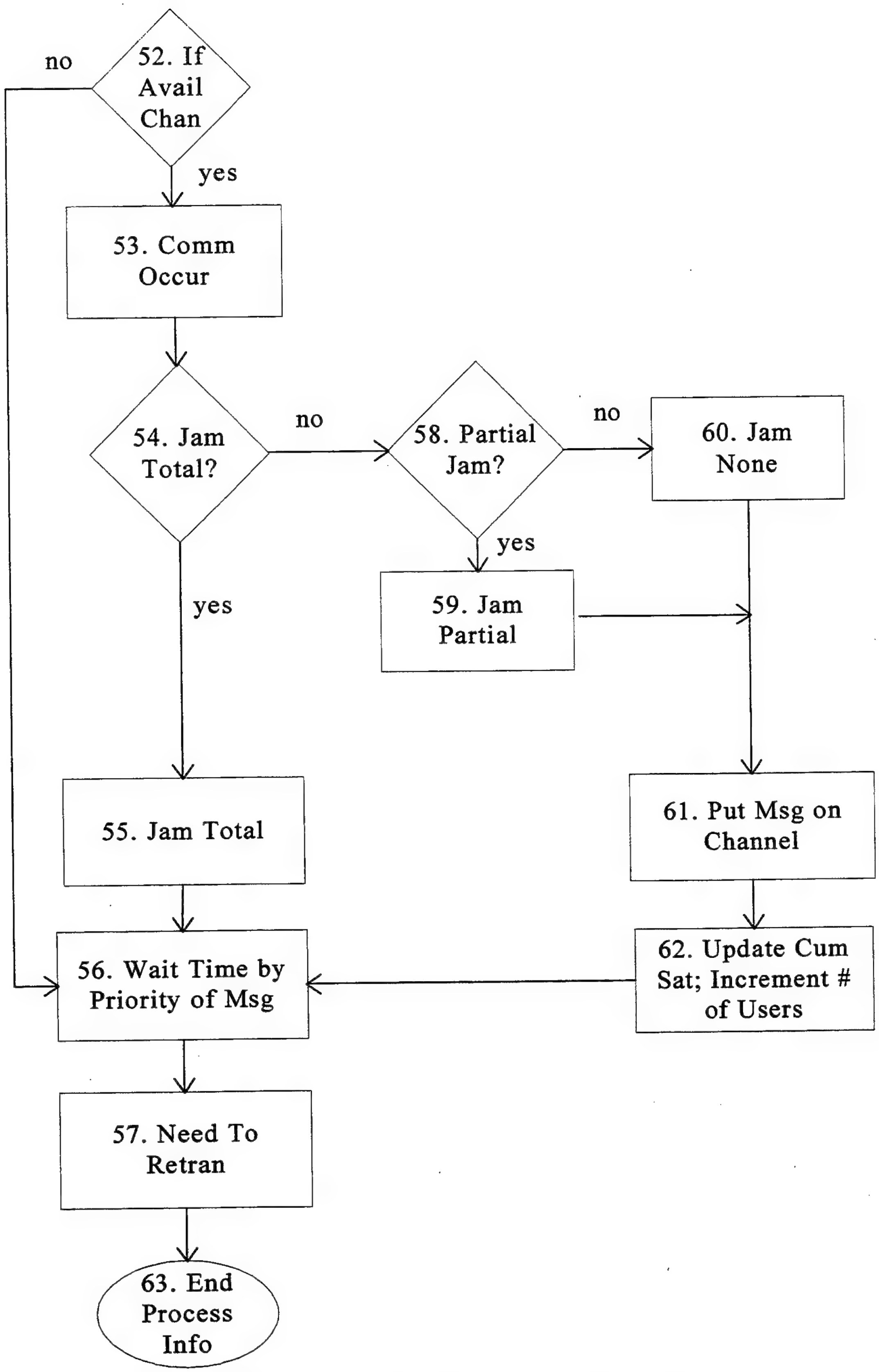

Figure 56. Process Information Flow Chart continued, Steps 52 – 63.

```
Sheets("type").Select
Done = False
Do Until Done
        If msgType = Cells(TRow, typCol).Value Then
                waitTime = Cells(TRow, typCol + 1).Value
                maxWaitTime = Cells(mxTrow, typCol + 1).Value
                Done = True
        Else
                TRow = TRow + 1
                mxTrow = mxTrow + 1
        End If
Loop
```

57. Need To Retransmit

Step 57 calls the procedure "NeedToRetrans". This procedure puts the message on the retransmission queue by copying the message information from "sim" sheet into the "Retrans" sheet. It puts a "w" in the *status* column in the "Retrans" sheet to indicate that the message is waiting to be retransmitted, or, if the message was a retry message, it puts an "n" indicating that the message was a retransmission. The procedure also puts the maximum time to keep trying to send the message and the amount of time to wait prior to retransmitting a message into the retransmission queue. The following is an excerpt from this procedure.

```
Sheets("Retrans").Select
RetRow = Cells(2, 2).Value
tmcol = 12
mxTmCol = 20
Sheets("sim").Select
curMsgNum = Cells(curRow, 2).Value
MsgNumRow curMsgNum, origMsgRow, origMsgTime 'determines original message row on
        "sim"
Sheets("sim").Select
Cells(curRow, 1).Select
Selection.copy
Sheets("Retrans").Select
Cells(RetRow, 1).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
SkipBlanks:=False, Transpose:=False
Sheets("sim").Select
Set sr1 = Range(Cells(curRow, 2), Cells(curRow, 3))
```

```
Set sr2 = Range(Cells(curRow, 4), Cells(curRow, 5))
Set sr3 = Range(Cells(curRow, 6), Cells(curRow, 7))
Set sr4 = Range(Cells(curRow, 8), Cells(curRow, 9))
Set sr5 = Range(Cells(curRow, 10), Cells(curRow, 11))
Set simRng = Union(sr1, sr2, sr3, sr4, sr5)
simRng.Select
Selection.copy
Sheets("Retrans").Select
Set r1 = Range(Cells(RetRow, 2), Cells(RetRow, 3))
Set r2 = Range(Cells(RetRow, 4), Cells(RetRow, 5))
Set r3 = Range(Cells(RetRow, 6), Cells(RetRow, 7))
Set r4 = Range(Cells(RetRow, 8), Cells(RetRow, 9))
Set r5 = Range(Cells(RetRow, 10), Cells(RetRow, 11))
Set retRng = Union(r1, r2, r3, r4, r5)
retRng.Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
SkipBlanks:=False, Transpose:=False
Cells(RetRow, tmcol).Value = waitTime
Cells(RetRow, mxTmCol).Value = maxWaitTime
Sheets("sim").Select
If Cells(curRow, rcol).Value = "r" Then
        status = "n"
        RetMsgNumRow curMsgNum, RetOrigRow
        Sheets("Retrans").Select
        Cells(RetOrigRow, 15).Value = timLastTry 'puts time last tried to trans in orig msg row
        Cells(RetOrigRow, 13).Value = Cells(RetOrigRow, tmcol).Value + Cells(RetOrigRow,
                15).Value
Else
        status = "w"
        Sheets("Retrans").Select
        Cells(RetRow, 15).Value = timLastTry
        Cells(RetRow, 13).Value = Cells(RetRow, tmcol).Value + Cells(RetRow, 15).Value
        Cells(RetRow, 21).Value = Cells(RetRow, 1).Value + Cells(RetRow, mxTmCol).Value
End If
Sheets("sim").Select
Cells(curRow, cnum).Value = "w"
satUp = Cells(curRow, 14).Value
satDown = Cells(curRow, 17).Value
RandNum = Cells(curRow, 12).Value
jam = Cells(curRow, 27).Value
Sheets("Retrans").Select
Cells(RetRow, cRetstat).Value = status
Cells(RetRow, 16).Value = satUp
Cells(RetRow, 17).Value = satDown
Cells(RetRow, 18).Value = RandNum
Cells(RetRow, 19).Value = jam
Cells(2, 2).Value = RetRow + 1
```

58. Check for Jam Partial

Step 58 checks to see if the message is partially jammed. If it was, then continue with Step 59; otherwise, go to Step 60.

59. Jam Partial

Step 59 puts a "pj" on the "sim" sheet to indicate that the message was partially jammed. Following this step, go to Step 61. The following is an excerpt from this procedure.

```
Sheets("sim").Select
Cells(curRow, jcol).Value = "pj"
Cells(curRow, ccol).Value = "pj" 'indicates message is being partially jammed
timLastTry = Cells(curRow, 1).Value
PutTransOnChan curRow   'puts the transmission on the channel that is trans on "time"
IncNumUsers curRow      'increments # of cum users on "sat chan"
If (Not ack) Then
        WaitTimePri waitTime, msgType, maxWaitTime
        NeedToRetrans waitTime, curRow, maxWaitTime, timLastTry 'puts message into the
                        retransmission queue
End If
```

60. Jam None

If the message was not jammed either partially or completely, a "good" is placed in the *status* column on the "sim" sheet. The following is an excerpt from this procedure.

```
Sheets("sim").Select
Cells(curRow, jcol).Value = "good"
Cells(curRow, ccol).Value = "t" 'indicates message transmitting good on sim sheet
timLastTry = Cells(curRow, 1).Value
PutTransOnChan curRow  'puts the transmission on the channel that is transmitting on sheet
        time
IncNumUsers curRow  'increments the cumulative number of users on a satellite on sheet sat
        chan
If (Not ack) Then
        WaitTimePri waitTime, msgType, maxWaitTime
        NeedToRetrans waitTime, curRow, maxWaitTime, timLastTry
End If
```

61. Put Transmission on Channel

Step 61 puts the message on the "time" sheet indicating that the message is transmitting by the "PutTransOnChan" procedure. It puts the message on both the uplink

and downlink satellites. The procedure copies the message information from "sim" sheet to the "time" sheet.

```
AvailChanNum ChUp, ChDown, RChUp, RChDown, ColChUp, ColChDown, curRow
Sheets("sim").Select
satUp = Cells(curRow, cnumUp).Value
satDown = Cells(curRow, cnumDown).Value
Cells(curRow, cnumMsg).Select
Selection.copy
Sheets("time").Select
Cells(RChUp, ColChUp).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
SkipBlanks:=False, Transpose:=False
Sheets("sim").Select
curTime = Cells(curRow, 1).Value
Cells(curRow, cnumtm).Select
Selection.copy
Sheets("time").Select
Cells(RChUp, ColChUp + 1).Select
Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
SkipBlanks:=False, Transpose:=False
Cells(RChUp, ColChUp + 2).Value = Cells(RChUp, ColChUp + 1).Value
Cells(RChUp, ColChUp + 3).Value = curTime
If satUp <> satDown Then
        Sheets("sim").Select
        Cells(curRow, cnumMsg).Select
        Selection.copy
        Sheets("time").Select
        Cells(RChDown, ColChDown).Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
        Sheets("sim").Select
        Cells(curRow, cnumtm).Select
        Selection.copy
        Sheets("time").Select
        Cells(RChDown, ColChDown + 1).Select
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, _
        SkipBlanks:=False, Transpose:=False
        Cells(RChDown, ColChDown + 2).Value = Cells(RChDown, ColChDown).Value
        Cells(RChDown, ColChDown + 3).Value = curTime
End If
```

62. Increment Number of Users

Step 62 updates the "sat chan" sheet. The procedure, "IncNumUsers", increments the number of users of the satellite that is transmitting by one. It does this for both the up

and downlink satellites. After executing this procedure the program goes to Step 55. The following is an extract from this procedure.

```
Sheets("sat chan").Select
curRow = Cells(9, 2).Value
AvailChanNum ChUp, ChDown, RChUp, RChDown, CChUp, CChDown, simRow
Sheets("sim").Select
satUp = Cells(simRow, cnumUp).Value
satDown = Cells(simRow, cnumDown).Value
Sheets("sat chan").Select
prevtime = Cells(curRow - 1, tmcol).Value
Cells(curRow, tmcol).Value = prevtime + 1   'increases time value in "sat chan"
ColChUp = satUp * 2
ColChDown = satDown * 2
incUp = Cells(curRow, ColChUp).Value
Cells(curRow, ColChUp).Value = incUp + 1
If satUp <> satDown Then
        incDown = Cells(curRow, ColChDown).Value
        Cells(curRow, ColChDown).Value = incDown + 1
End If
nxtRow = curRow + 1
Cells(9, 2).Value = nxtRow
UpdateCumSat curRow
UpdateCumSat nxtRow
```

63. End

Step 63 ends "processInfo". Program control is returned to the appropriate step (i.e., Step 17, 33, or 43).

APPENDIX B. SUMMARY STATUS FOR NUMBER OF MESSAGES TRANSMITTED

The number of messages transmitted "good", "stopG", and "stopNG" for Case 1 is shown in Figures 57 - 61.

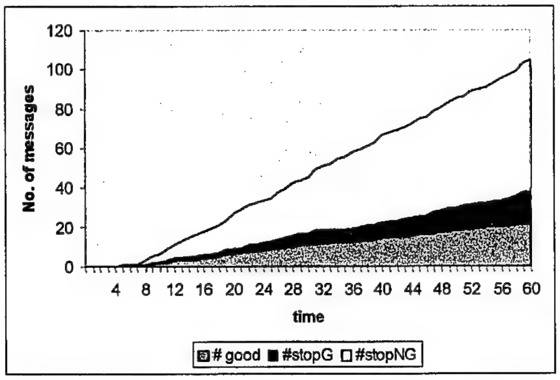

Figure 57. Case 1: Priority 1.

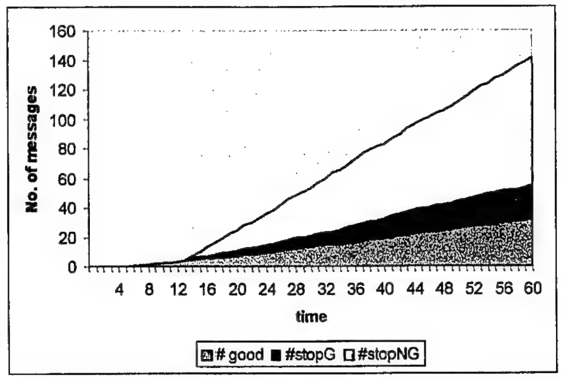

Figure 58. Case 1: Priority 2.

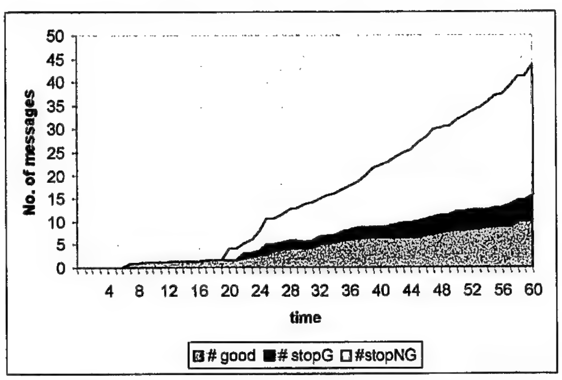

Figure 59. Case 1: Priority 3.

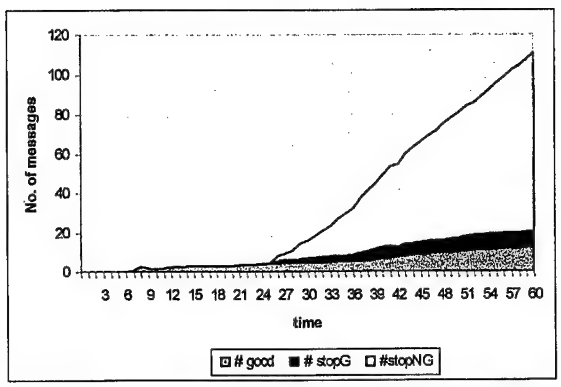

Figure 60. Case 1: Priority 4.

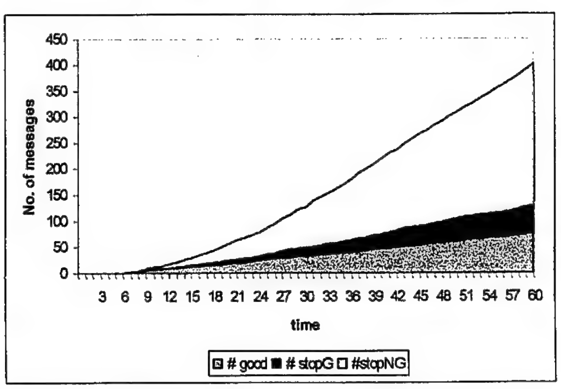

Figure 61. Case 1: All Messages.

The number of messages transmitted "good", "stopG", and "stopNG" for Case 2 is shown in Figures 62 - 66.

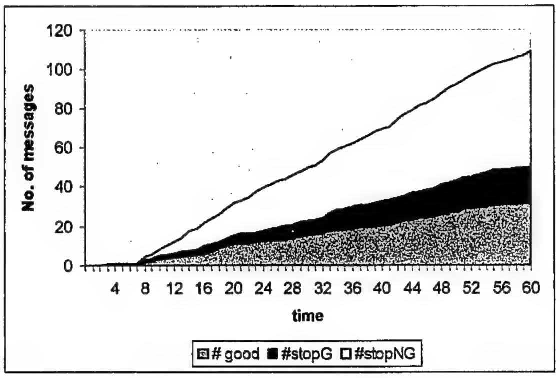

Figure 62. Case 2: Priority 1.

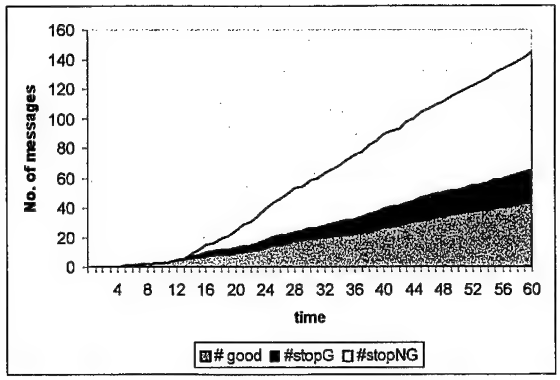

Figure 63. Case 2: Priority 2.

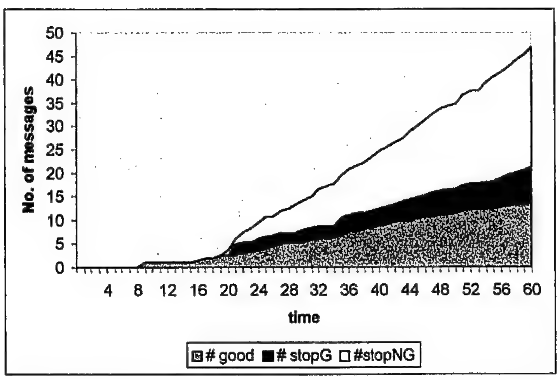

Figure 64. Case 2: Priority 3.

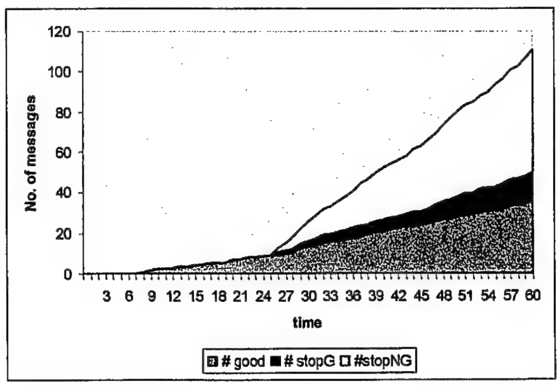

Figure 65. Case 2: Priority 4.

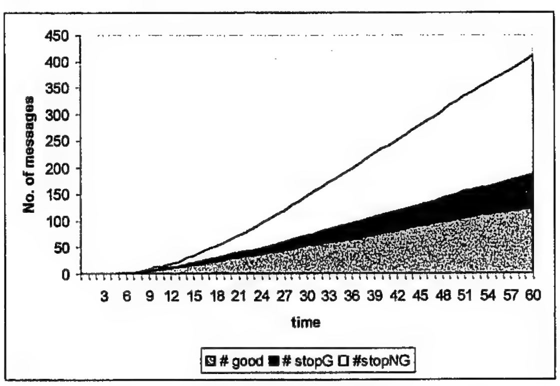

Figure 66. Case 2: All Messages.

The number of messages transmitted “good”, “stopG”, and “stopNG” for Case 3 is shown in Figures 67 - 71.

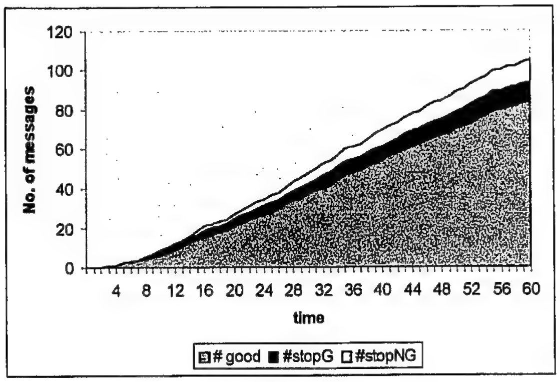

Figure 67. Case 3: Priority 1.

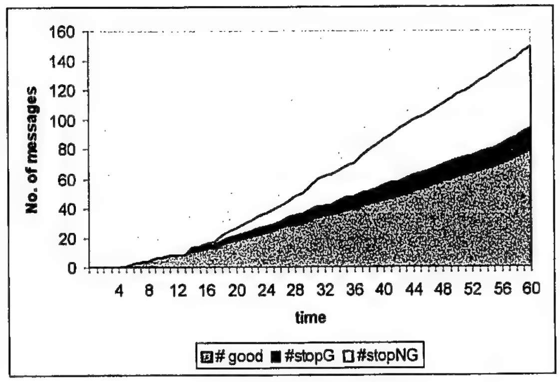

Figure 68. Case 3: Priority 2.

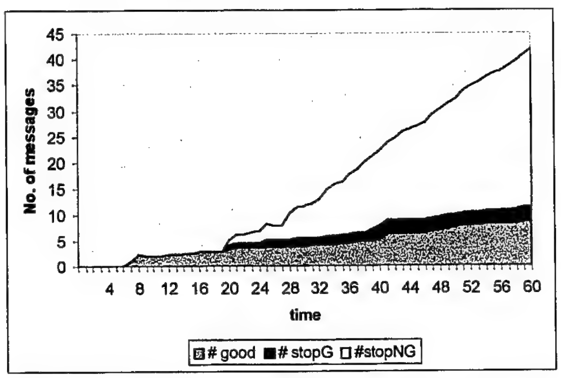

Figure 69. Case 3: Priority 3.

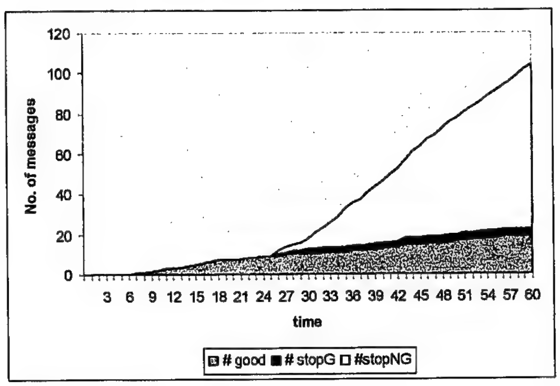

Figure 70. Case 3: Priority 4.

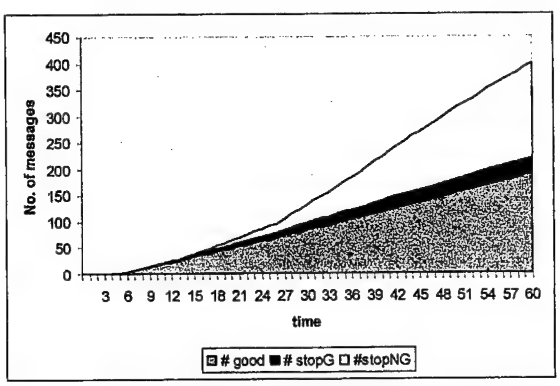

Figure 71. Case 3: All Messages

The number of messages transmitted "good", "stopG", and "stopNG" for Case 4 is shown in Figures 72 - 76.

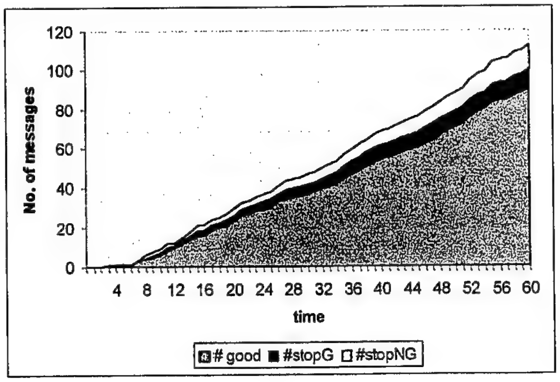

Figure 72. Case 4: Priority 1.

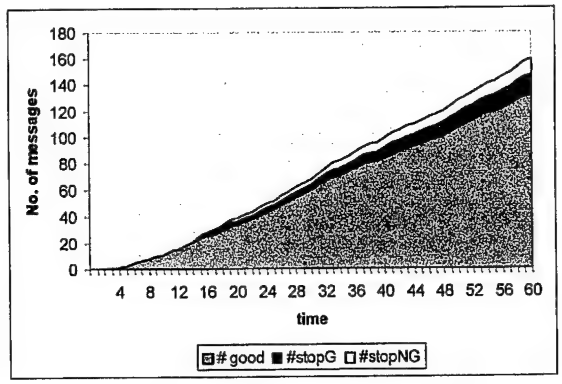

Figure 73. Case 4: Priority 2.

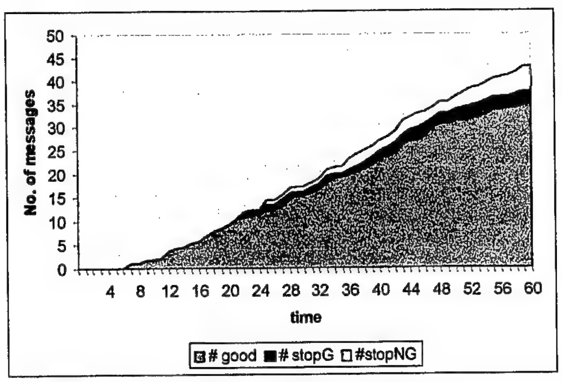

Figure 74. Case 4: Priority 3.

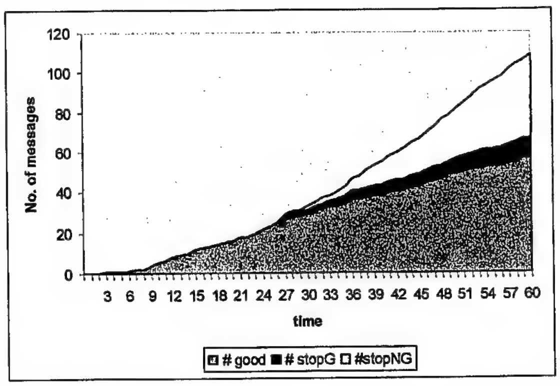

Figure 75. Case 4: Priority 4.

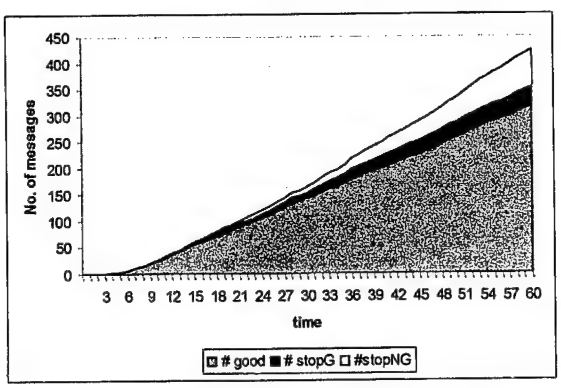

Figure 76. Case 4: All Messages.

APPENDIX C. NUMBER OF CHANNELS IN USE OVER TIME

The number of channels in use over time for Case 1 is shown in Figures 77 - 81.

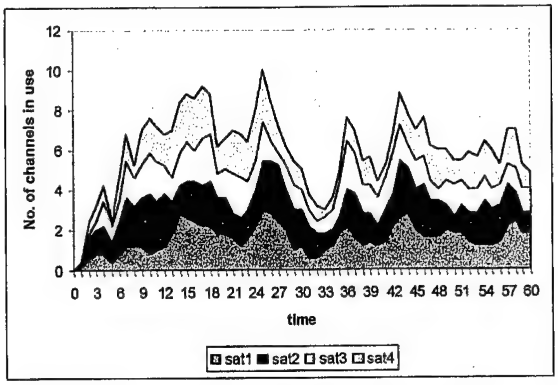

Figure 77. Case 1: Priority 1.

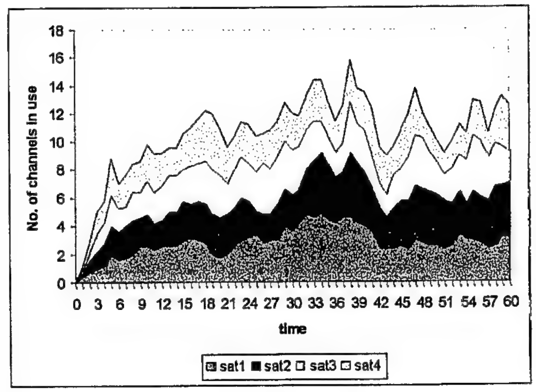

Figure 78. Case 1: Priority 2.

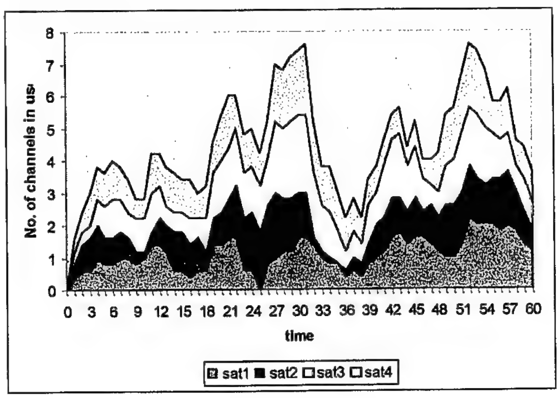

Figure 79. Case 1: Priority 3.

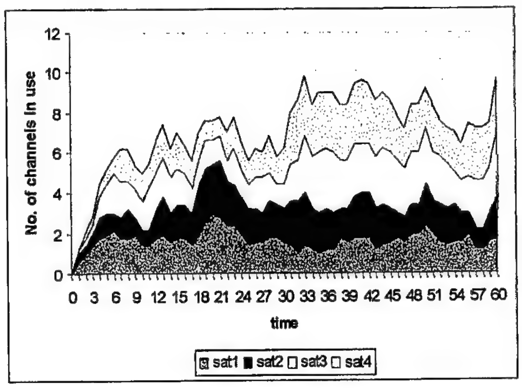

Figure 80. Case 1: Priority 4.

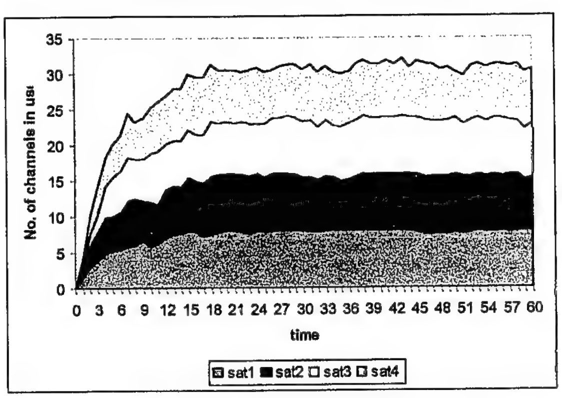

Figure 81. Case 1: All Messages.

The number of channels in use over time for Case 2 is shown in Figures 82 - 86.

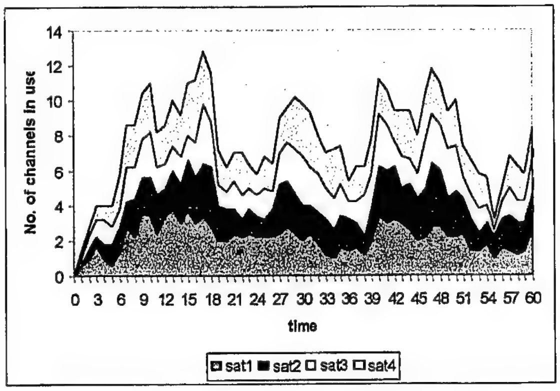

Figure 82. Case 2: Priority 1.

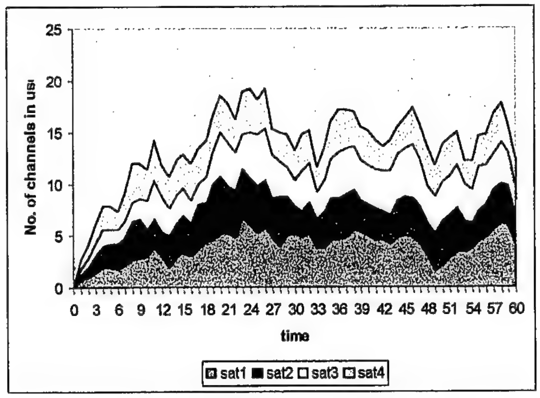

Figure 83. Case 2: Priority 2.

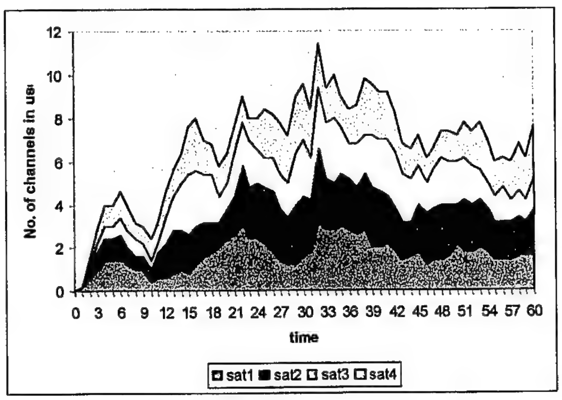

Figure 84. Case 2: Priority 3.

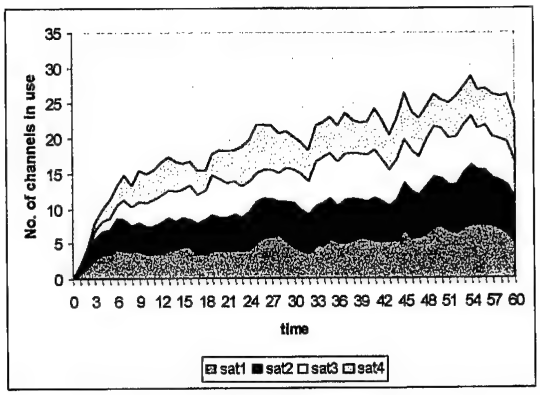

Figure 85. Case 2: Priority 4.

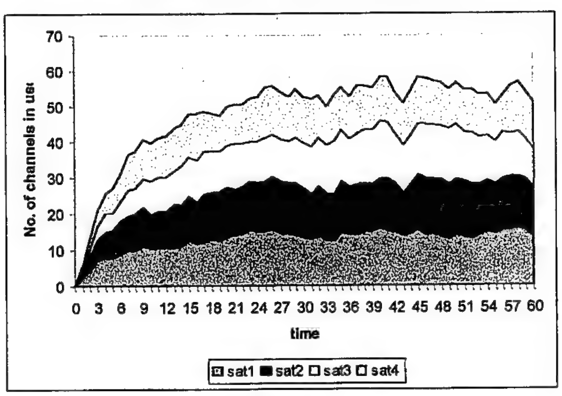

Figure 86. Case 2: All Messages.

The number of channels in use over time for Case 3 is shown in Figures 87 - 91.

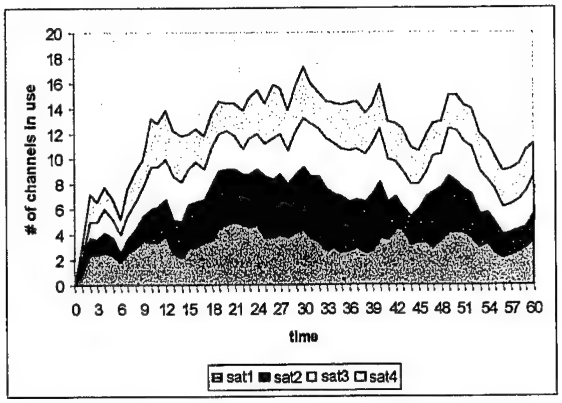

Figure 87. Case 3: Priority 1.

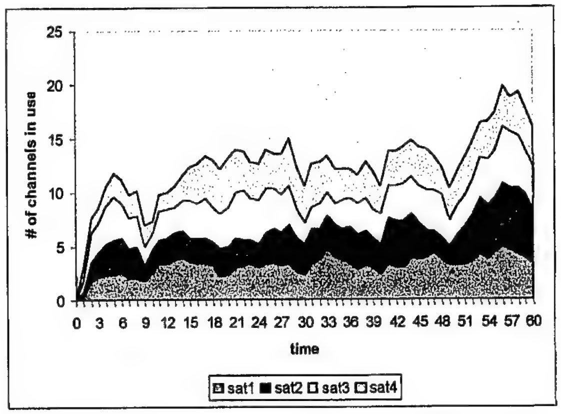

Figure 88. Case 3: Priority 2.

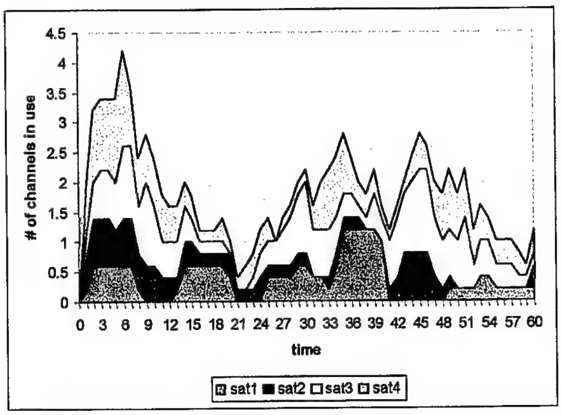

Figure 89. Case 3: Priority 3.

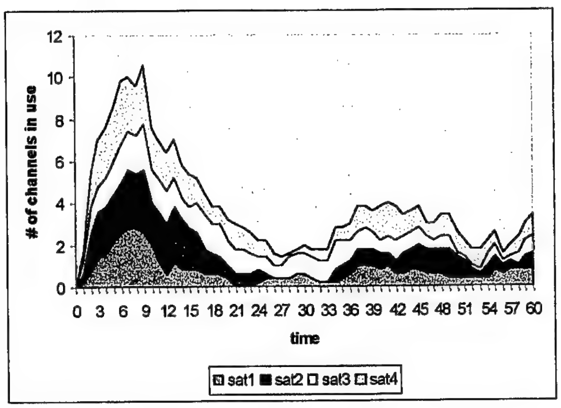

Figure 90. Case 3: Priority 4.

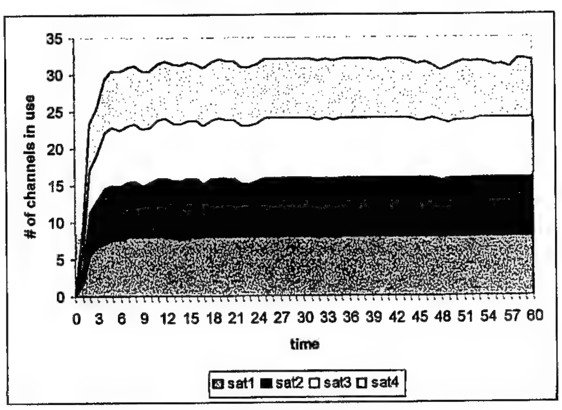

Figure 91. Case 3: All Messages.

The number of channels in use over time for Case 4 is shown in Figures 92 - 96.

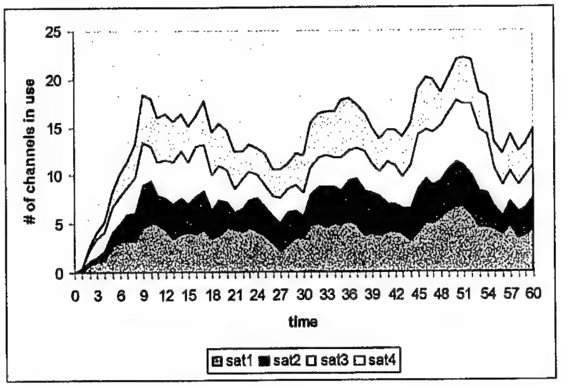

Figure 92. Case 4: Priority 1.

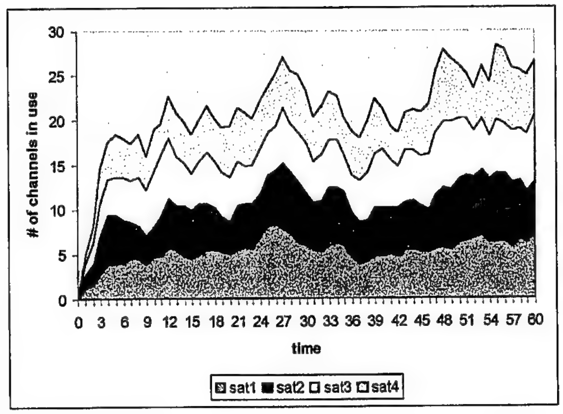

Figure 93. Case 4: Priority 2.

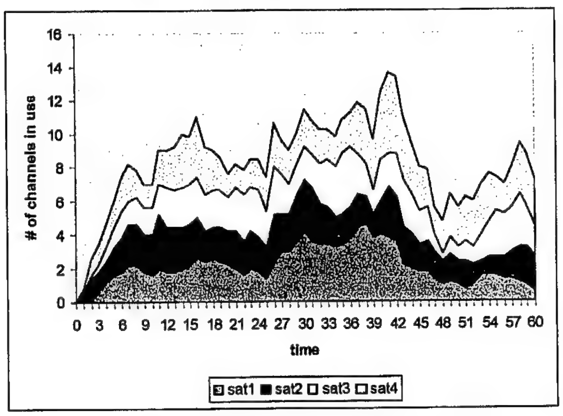

Figure 94. Case 4: Priority 3.

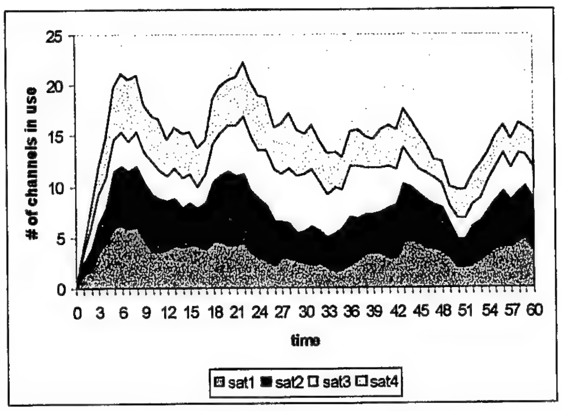

Figure 95. Case 4: Priority 4.

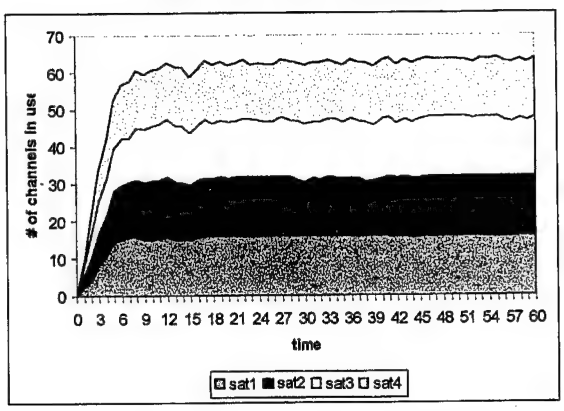

Figure 96. Case 4: All Messages.

APPENDIX D. CUMULATIVE AND AVERAGE NUMBER OF MESSAGES GENERATED

The cumulative number of messages generated by priority and the average number of messages generated over time is shown by case in Figures 97 - 102.

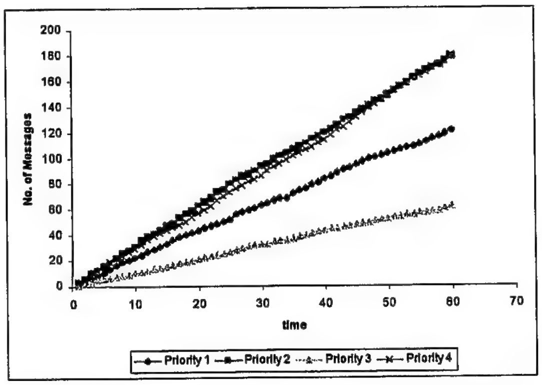

Figure 97. Case 2.

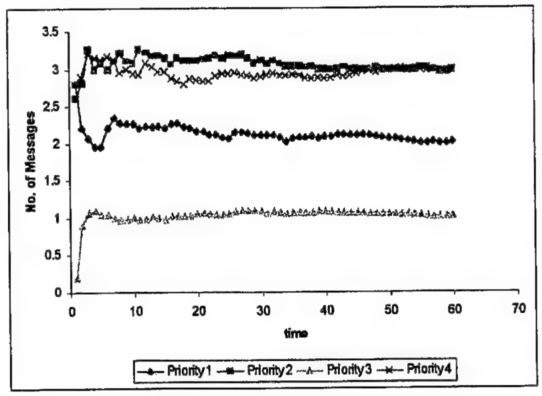

Figure 98. Case 2.

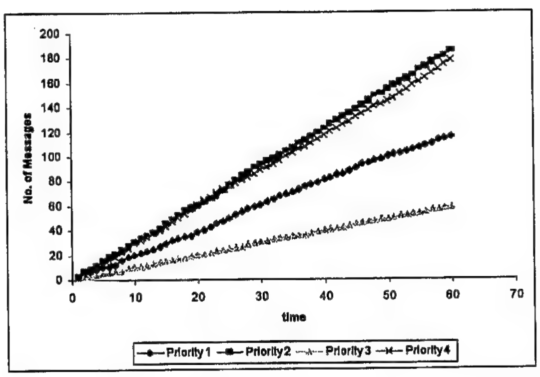

Figure 99. Case 3.

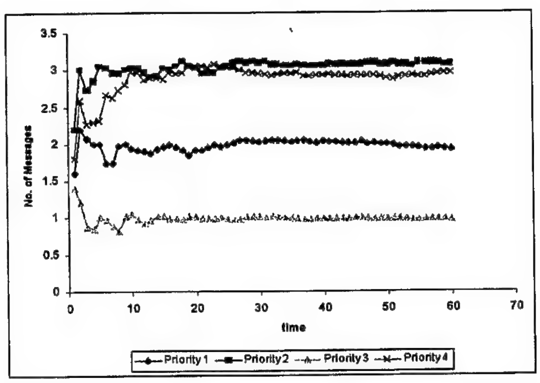

Figure 100. Case 3.

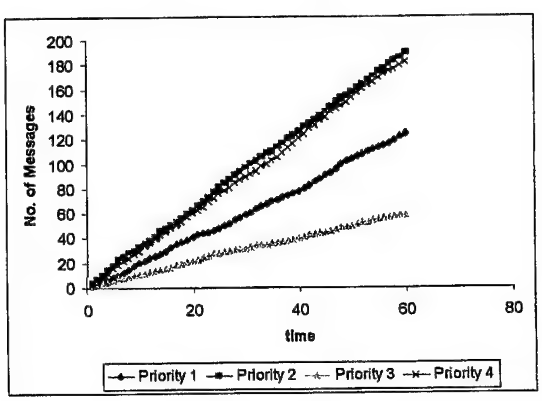

Figure 101. Case 4.

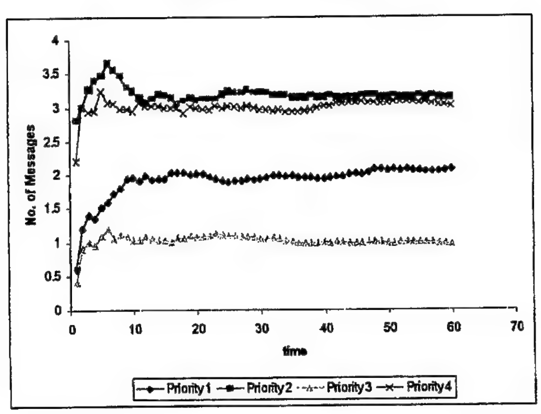

Figure 102. Case 4.

APPENDIX E. SUMMARY STATISTICS

The following are the summary statistics for runs of the model.

Case1	cum chan used time 60					# good trans					# stopG				
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	8	8	8	7	**31**	27	23	12	9	71	13	20	5	5	**43**
run 2	8	8	7	8	**31**	29	55	14	25	**123**	16	17	4	4	**41**
run 3	8	8	8	8	**32**	12	36	12	9	**69**	19	28	5	9	**61**
run 4	8	5	7	8	**28**	16	19	5	4	**44**	15	29	6	15	**65**
run 5	8	8	7	8	**31**	24	28	9	13	**74**	19	18	6	11	**54**
Mean	8	7.4	7.4	7.8	**30.6**	21.6	32.2	10.4	12	**76.2**	16.4	22.4	5.2	8.8	**52.8**
Var	0	1.8	0.3	0.2	**2.3**	53.3	202.7	12.3	63	**827.7**	6.8	32.3	0.7	20.2	**113.2**
stdev	0	1.3416	0.5477	0.4472	**1.51658**	7.30068	14.237	3.5071	7.937	**28.77**	2.6077	5.683	8367	4.494	**10.64**

Case1	#stopNG					gd/tot#msgs					Time to transmit gd msgs				
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	77	84	34	96	**291**	0.20611	0.1429	0.1846	0.0511	**0.1332**	5.9259	9.087	11	10.11	**8.33803**
run 2	50	67	26	86	**229**	0.28431	0.3056	0.2154	0.1344	**0.2308**	5.5172	8.673	13.5	11.84	**9.12195**
run 3	75	86	26	93	**280**	0.10345	0.1935	0.2143	0.0492	**0.1275**	6.1667	7.694	10.9	14.56	**8.88406**
run 4	61	103	34	98	**296**	0.16162	0.0941	0.0806	0.0211	**0.0796**	5.25	8.632	15.4	17.75	**9**
run 5	71	97	20	78	**266**	0.192	0.1538	0.18	0.0760	**0.1402**	5.7917	7.821	14.3	16.77	**9.52703**
Mean	66.8	87.4	28	90.2	**272.4**	0.18950	0.1780	0.1750	0.0664	**0.1423**	5.7303	8.381	13.0	14.21	**8.97421**
Var	126.2	191.3	36	67.2	**721.3**	0.00436	0.0063	0.0030	0.0018	**0.0030**	0.1271	0.358	4.03	10.40	**0.18524**
stdev	11.234	13.831	6	8.1976	**26.857**	0.06605	0.0796	0.0552	0.0427	**0.0549**	0.3566	0.598	2.01	3.226	**0.43039**

Case2	cum chan used time 60					# good trans					# stopG				
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	16	13	16	16	**61**	18	36	10	22	**86**	22	23	10	15	**70**
run 2	16	16	8	12	**52**	41	51	15	44	**151**	19	15	7	17	**58**
run 3	12	9	12	16	**49**	29	46	18	40	**133**	15	25	6	11	**57**
run 4	8	16	8	11	**43**	35	55	12	48	**150**	19	27	4	19	**69**
run 5	16	13	9	13	**51**	35	30	14	27	**106**	16	18	11	8	**53**
Mean	13.6	13.4	10.6	13.6	**51.2**	31.6	43.6	13.8	36.2	**125.2**	18.2	21.6	7.6	14	**61.4**
Var	12.8	8.3	11.8	5.3	**42.2**	75.8	108.3	9.2	125.2	**811.7**	7.7	24.8	8.3	20	**58.3**
stdev	3.5777	2.8810	3.4351	2.3022	**6.49615**	8.70632	10.407	3.0332	11.189	**28.490**	2.7749	4.980	2.88	4.472	**7.63544**

Case2	#stopNG					gd/tot#msgs					Time to transmit gd msgs				
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	65	87	34	70	**256**	0.15652	0.1915	0.1563	0.1152	**0.1541**	5.3889	8.083	11.4	14.68	**9.593**
run 2	57	74	26	56	**213**	0.30597	0.3054	0.2459	0.2486	**0.2802**	5.4634	8.529	9.27	14.20	**9.424**
run 3	59	75	24	69	**227**	0.30435	0.2910	0.24	0.2682	**0.2814**	5.2414	7.761	9.83	11.6	**8.647**
run 4	47	75	18	51	**191**	0.30435	0.2910	0.24	0.2682	**0.2814**	5.3143	6.945	9.58	12.85	**8.667**
run 5	67	88	25	56	**236**	0.28	0.1786	0.2059	0.1579	**0.1993**	5.8857	9	11.6	16.15	**10.14**
Mean	59	79.8	25.4	60.4	**224.6**	0.27024	0.2515	0.2176	0.2116	**0.2393**	5.4587	8.064	10.3	13.90	**9.294**
Var	62	49.7	32.8	73.3	**596.3**	0.00416	0.0037	0.0014	0.0050	**0.0035**	0.0638	0.609	1.20	3.036	**0.409**
stdev	7.8740	7.0498	5.7271	8.5615	**24.4193**	0.06448	0.0611	0.0378	0.0706	**0.0593**	0.2526	0.78	1.10	1.742	**0.64**

Case3	cum chan used time 60					# good trans					# stopG				
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	8	8	8	8	**32**	104	68	5	19	**196**	16	13	0	4	**33**
run 2	8	8	8	8	**32**	65	86	11	14	**176**	8	8	6	5	**27**
run 3	8	8	8	8	**32**	76	94	13	16	**199**	8	16	1	5	**30**
run 4	8	8	8	7	**31**	86	76	7	21	**190**	10	20	2	1	**33**
run 5	8	8	8	8	**32**	89	71	7	24	**191**	7	16	2	2	**27**
Mean	8	8	8	7.8	**31.8**	84	79	8.6	18.8	**190.4**	9.8	14.6	2.2	3.4	**30**
Var	0	0	0	0.2	**0.2**	213.5	117	10.8	15.7	**78.3**	13.2	19.8	5.2	3.3	**9**
stdev	0	0	0	0.4472	**0.44721**	14.6116	10.817	3.2863	3.9623	**8.8487**	3.6332	4.450	2.28	1.816	**3**

Case3			#stopNG					gd/tot#msgs					Time to transmit gd msgs		
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	14	75	31	85	**205**	0.7075	0.3452	0.0877 2	0.1027	**0.3345**	6.5673	9.294	9.8	14.16	**8.332**
run 2	15	41	34	77	**167**	0.6373	0.5	0.1719	0.08	**0.3431**	6.0154	10.03	13.5	13.93	**9.074**
run 3	10	50	25	94	**179**	0.7755	0.4974	0.2241	0.0879	**0.3776**	6.0154	10.03	13.5	13.93	**9.074**
run 4	7	43	36	78	**164**	0.7611	0.4222	0.1207	0.1235	**0.3647**	6.0154	10.03	13.5	13.93	**9.074**
run 5	12	68	27	76	**183**	0.7607	0.3817	0.1273	0.1341	**0.3557**	6.0154	10.03	13.5	13.93	**9.074**
Mean	11.6	55.4	30.6	82	**179.6**	0.7284	0.4293	0.1463	0.1056	**0.3551**	6.1258	9.887	12.7	13.97	**8.925**
Var	10.3	233.3	21.3	57.5	**264.8**	0.0033	0.0048	0.0028	0.0005	**0.0003**	0.0609	0.11	2.67	0.010	**0.11**
stdev	3.2094	15.274	4.6152	7.5829	**16.2727**	0.0572	0.069	0.0528	0.023	**0.0171**	0.2468	0.331	1.63	0.103	**0.332**

Case4		cum chan used time 60						# good trans					# stopG		
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	16	16	16	16	**64**	81	137	33	59	**310**	13	12	2	11	**38**
run 2	16	16	16	16	**64**	94	125	35	58	**312**	7	22	2	11	**42**
run 3	16	16	16	16	**64**	89	135	34	58	**316**	8	13	5	8	**34**
run 4	16	15	16	16	**63**	97	135	37	52	**321**	11	6	3	10	**30**
run 5	16	16	16	16	**64**	91	129	36	59	**315**	9	23	2	8	**42**
Mean	16	15.8	16	16	**63.8**	90.4	132.2	35	57.2	**314.8**	9.6	15.2	2.8	9.6	**37.2**
Var	0	0.2	0	0	**0.2**	36.8	25.2	2.5	8.7	**17.7**	5.8	51.7	1.7	2.3	**27.2**
stdev	0	0.4472	0	0	**0.44721**	6.0663	5.0199	1.5811	2.9496	**4.2071**	2.4083	7.190	1.30	1.517	**5.21536**

Case4			#stopNG					gd/tot#msgs					Time to transmit gd msgs		
	sat 1	sat 2	sat 3	sat 4	**total**	p1	p2	p3	p4	**total**	p1	p2	p3	p4	**total**
run 1	14	15	2	32	**63**	0.7043	0.699	0.6875	0.3391	**0.5816**	5.8765	8.036	13.4	14.41	**9.255**
run 2	11	13	12	50	**86**	0.7705	0.6477	0.5147	0.2959	**0.5389**	5.8765	8.036	13.4	14.41	**9.255**
run 3	11	9	6	33	**59**	0.7417	0.7337	0.5763	0.3295	**0.5863**	5.8765	8.036	13.4	14.41	**9.255**
run 4	11	14	2	50	**77**	0.7405	0.7542	0.6271	0.2889	**0.5847**	5.8765	8.036	13.4	14.41	**9.255**
run 5	15	10	4	43	**72**	0.6842	0.6754	0.6429	0.3224	**0.5595**	5.8765	8.036	13.4	14.41	**9.255**
Mean	12.4	12.2	5.2	41.6	**71.4**	0.7282	0.702	0.6097	0.3152	**0.5702**	5.8765	8.036	13.4	14.41	**9.255**
Var	3.8	6.7	17.2	77.3	**117.3**	0.0012	0.0018	0.0044	0.0005	**0.0004**	0	0	0	0	**1E-14**
stdev	1.9494	2.5884	4.1473	8.792	**10.8305**	0.034	0.043	0.0663	0.0217	**0.0206**	0	0	0	0	**1E-07**

APPENDIX F. ANALYSIS OF VARIANCE RESULTS

The Analysis of Variance results for the model are shown in Tables 12 - 16.

All msgs

 # good trans

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	115368.1	115368.1	265.9169	4.494
Chan	1	37584.45	37584.45	86.63006	4.494
JxC	1	7106.45	7106.45	16.37997	4.494
Error	16	6941.6	433.85		
Total	19	167000.6			

#stopNG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	75645	75645	178.0197	4.494
Chan	1	30420	30420	71.5891	4.494
JxC	1	4560.2	4560.2	10.73178	4.494
Error	16	6798.8	424.925		
Total	19	117424			

 # stopG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	2761.25	2761.25	53.17766	4.494
Chan	1	312.05	312.05	6.009629	4.494
JxC	1	2.45	2.45	0.047183	4.494
Error	16	830.8	51.925		
Total	19	3906.55			

gd/tot#msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.369611	0.369611	203.8603	4.494
Chan	1	0.121767	0.121767	67.16105	4.494
JxC	1	0.017422	0.017422	9.609237	4.494
Error	16	0.029009	0.001813		
Total	19	0.537809			

Time to transmit gd msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.030014	0.030014	0.192912	4.494
Chan	1	0.64119	0.64119	4.121214	4.494
JxC	1	0.004113	0.004113	0.026438	4.494
Error	16	2.489323	0.155583		
Total	19	3.16464			

Table 18. ANOVA Results for All Messages.

Priority 1

 # good trans

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	18361.8	18361.8	193.5878	4.494
Chan	1	336.2	336.2	3.544544	4.494
JxC	1	16.2	16.2	0.170796	4.494
Error	16	1517.6	94.85		
Total	19	20231.8			

#stopNG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	12954.05	12954.05	256.1354	4.494
Chan	1	61.25	61.25	1.211073	4.494
JxC	1	92.45	92.45	1.827978	4.494
Error	16	809.2	50.575		
Total	19	13916.95			

 # stopG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	288.8	288.8	34.48358	4.494
Chan	1	3.2	3.2	0.38209	4.494
JxC	1	5	5	0.597015	4.494
Error	16	134	8.375		
Total	19	431			

gd/tot#msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.61568	0.61568	147.6016	4.494
Chan	1	0.149826	0.149826	35.9189	4.494
JxC	1	0.049587	0.049587	11.88777	4.494
Error	16	0.06674	0.004171		
Total	19	0.881832			

Time to transmit gd msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.826772	0.826772	13.12923	4.494
Chan	1	0.339027	0.339027	5.383792	4.494
JxC	1	0.000624	0.000624	0.009905	4.494
Error	16	1.007549	0.062972		
Total	19	2.173972			

Table 19. Priority 1 ANOVA Results.

Priority 2

 # good trans

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	22916.45	22916.45	202.2635	4.494
Chan	1	5216.45	5216.45	46.04104	4.494
JxC	1	2184.05	2184.05	19.2767	4.494
Error	16	1812.8	113.3		
Total	19	32129.75			

#stopNG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	12400.2	12400.2	103.1202	4.494
Chan	1	3225.8	3225.8	26.82578	4.494
JxC	1	1584.2	1584.2	13.17422	4.494
Error	16	1924	120.25		
Total	19	19134.2			

 # stopG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	252.05	252.05	7.839813	4.494
Chan	1	0.05	0.05	0.001555	4.494
JxC	1	2.45	2.45	0.076205	4.494
Error	16	514.4	32.15		
Total	19	768.95			

gd/tot#msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.61568	0.61568	147.6016	4.494
Chan	1	0.149826	0.149826	35.9189	4.494
JxC	1	0.049587	0.049587	11.88777	4.494
Error	16	0.06674	0.004171		
Total	19	0.881832			

Time to transmit gd msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	1.136027	1.136027	5.87814	4.494
Chan	1	3.375063	3.375063	17.46357	4.494
JxC	1	5.290529	5.290529	27.37476	4.494
Error	16	3.092208	0.193263		
Total	19	12.89383			

Table 20. Priority 2 ANOVA Results.

Priority 3

 # good trans

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	470.45	470.45	54.07471	4.494
Chan	1	1110.05	1110.05	127.592	4.494
JxC	1	661.25	661.25	76.00575	4.494
Error	16	139.2	8.7		
Total	19	2380.95			

#stopNG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	387.2	387.2	14.4343	4.494
Chan	1	980	980	36.53308	4.494
JxC	1	649.8	649.8	24.22367	4.494
Error	16	429.2	26.825		
Total	19	2446.2			

 # stopG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	76.05	76.05	19.13208	4.494
Chan	1	11.25	11.25	2.830189	4.494
JxC	1	4.05	4.05	1.018868	4.494
Error	16	63.6	3.975		
Total	19	154.95			

gd/tot#msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.165108	0.165108	56.61683	4.494
Chan	1	0.32001	0.32001	109.7342	4.494
JxC	1	0.221268	0.221268	75.87479	4.494
Error	16	0.04666	0.002916		
Total	19	0.753045			

Time to transmit gd msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	9.40052	9.40052	4.758203	4.494
Chan	1	5.072556	5.072556	2.567544	4.494
JxC	1	14.07058	14.07058	7.122017	4.494
Error	16	31.61032	1.975645		
Total	19	60.15397			

Table 21. Priority 3 ANOVA Results.

Priority 4

 # good trans

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	966.05	966.05	18.17592	4.494
Chan	1	4898.45	4898.45	92.16275	4.494
JxC	1	252.05	252.05	4.742239	4.494
Error	16	850.4	53.15		
Total	19	6966.95			

#stopNG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	911.25	911.25	13.2401	4.494
Chan	1	6160.05	6160.05	89.50309	4.494
JxC	1	140.45	140.45	2.040683	4.494
Error	16	1101.2	68.825		
Total	19	8312.95			

 # stopG

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	120.05	120.05	10.48472	4.494
Chan	1	162.45	162.45	14.18777	4.494
JxC	1	1.25	1.25	0.10917	4.494
Error	16	183.2	11.45		
Total	19	466.95			

gd/tot#msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.02551	0.02551	13.0608	4.494
Chan	1	0.157317	0.157317	80.54489	4.494
JxC	1	0.005166	0.005166	2.645008	4.494
Error	16	0.031251	0.001953		
Total	19	0.219243			

Time to transmit gd msgs

ANOVA

Source of variation	df	SS	MS	F	Fcrit
Jam	1	0.096814	0.096814	0.028791	4.494
Chan	1	0.0195	0.0195	0.005799	4.494
JxC	1	0.684107	0.684107	0.203443	4.494
Error	16	53.80232	3.362645		
Total	19	54.60274			

Table 22. Priority 4 ANOVA Results.

The interaction plots for the number of good messages transmitted ANOVA are shown in Figures 103 - 107.

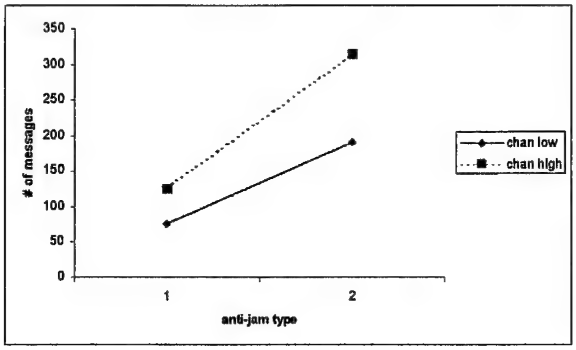

Figure 103. All Messages.

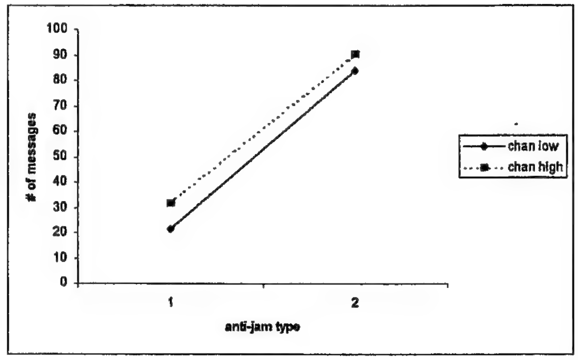

Figure 104. Priority 1.

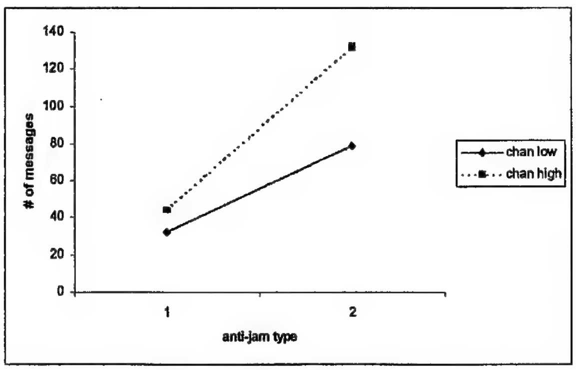

Figure 105. Priority 2.

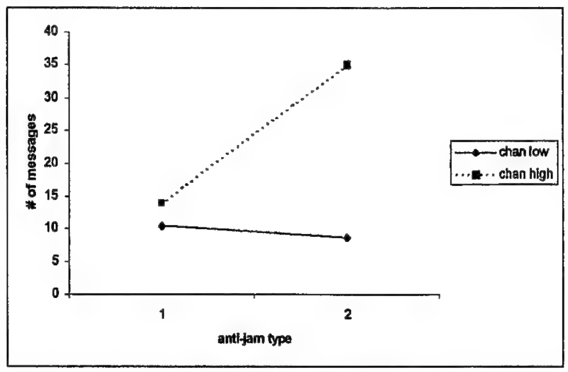

Figure 106. Priority 3.

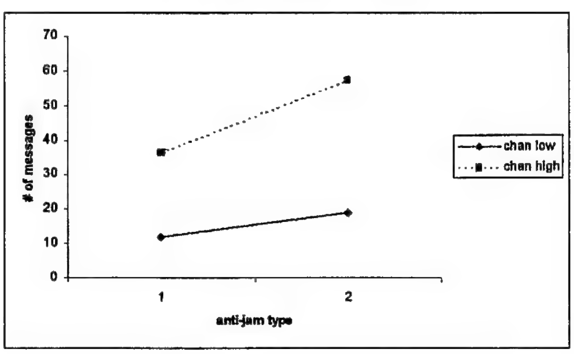

Figure 107. Priority 4.

The interaction plots for the number of messages "stopG" ANOVA are shown in Figures 108 - 112.

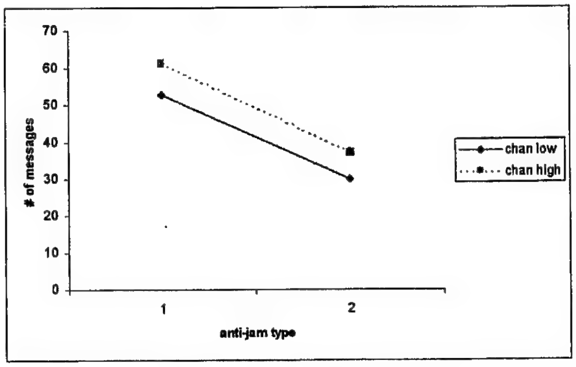

Figure 108. All Messages.

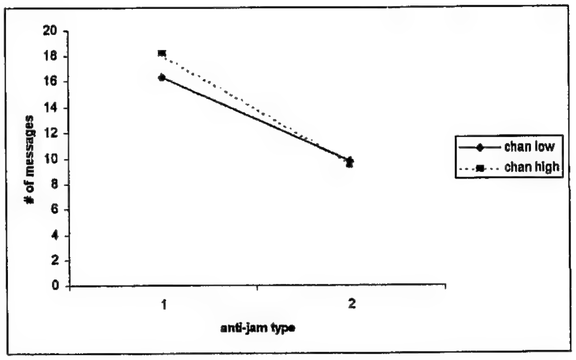

Figure 109. Priority 1.

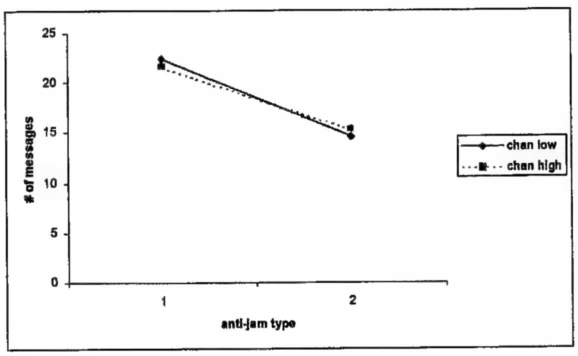

Figure 110. Priority 2.

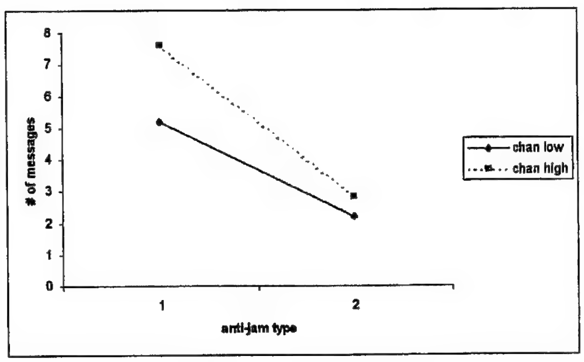

Figure 111. Priority 3.

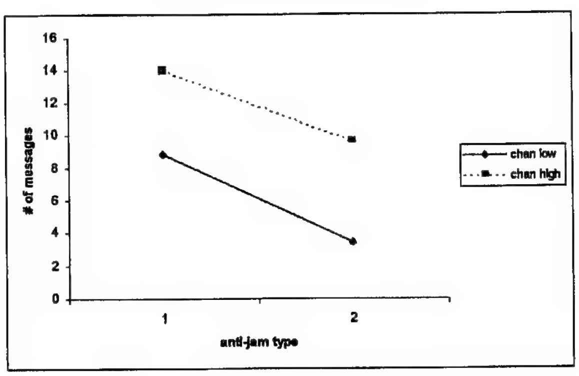

Figure 112. Priority 4.

The interaction plots for the number of messages "stopNG" ANOVA are shown in Figures 113 - 117.

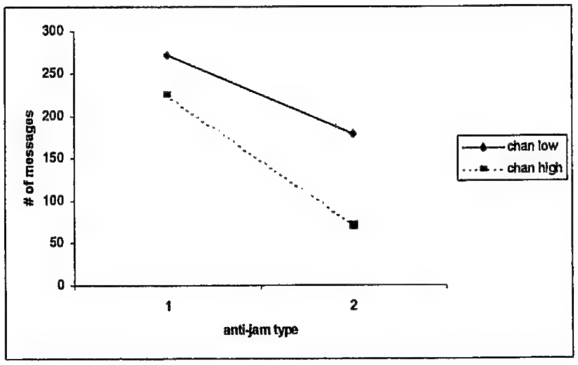

Figure 113. All Messages.

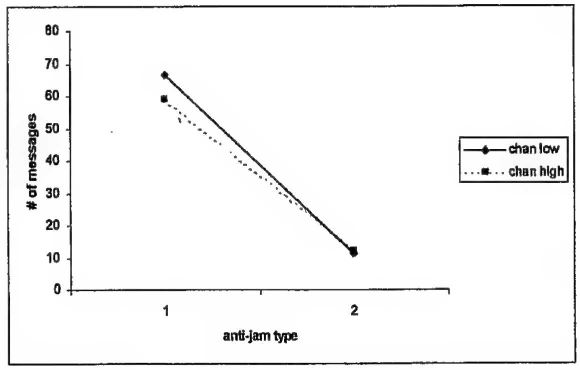

Figure 114. Priority 1.

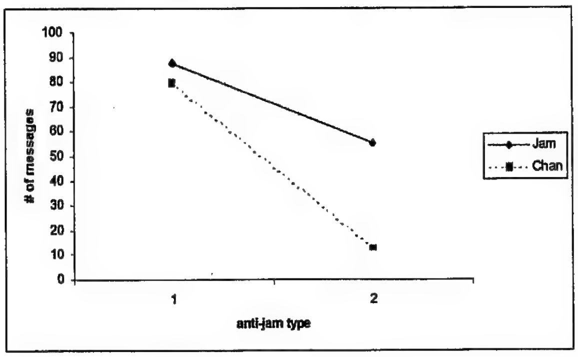

Figure 115. Priority 2.

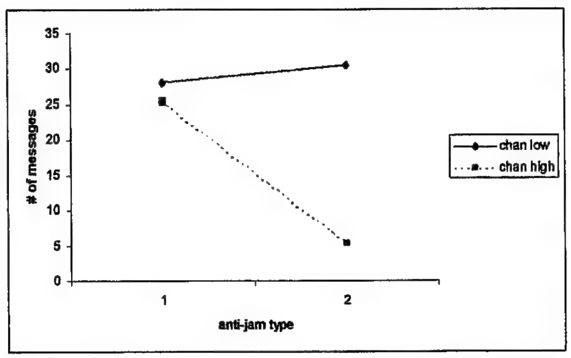

Figure 116. Priority 3.

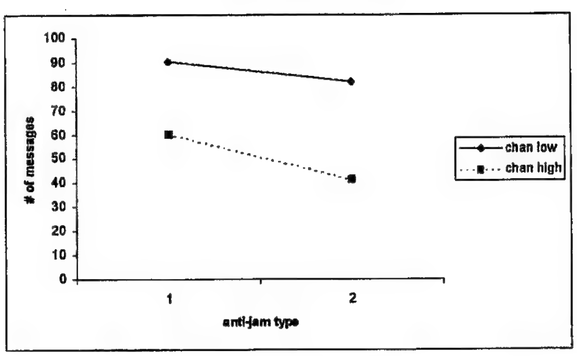

Figure 117. Priority 4.

The interaction plots for the number of good messages transmitted / number of messages generated ANOVA are shown in Figures 118 - 122.

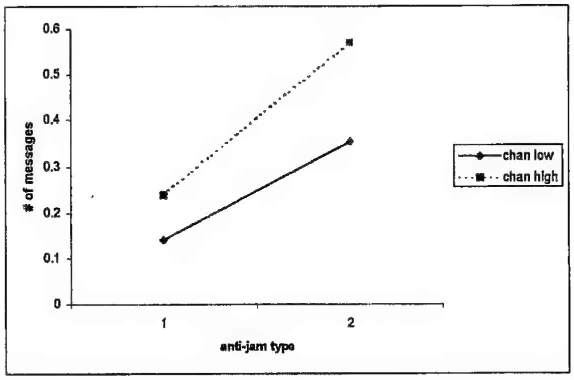

Figure 118. All messages.

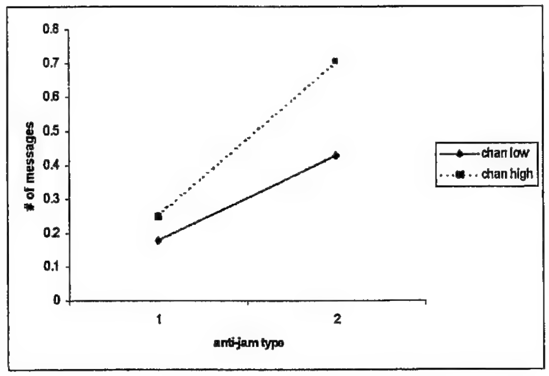

Figure 119. Priority 1.

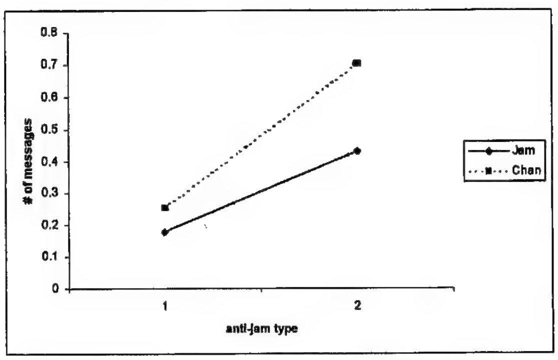

Figure 120. Priority 2.

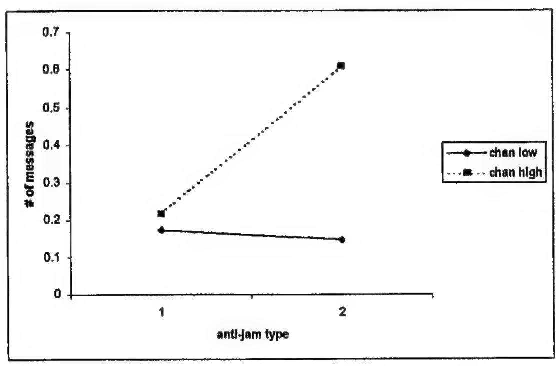

Figure 121. Priority 3.

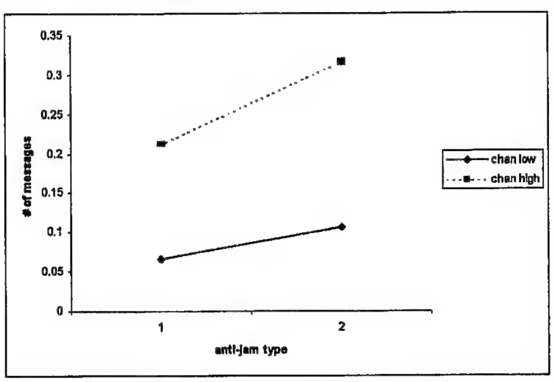

Figure 122. Priority 4.

The interaction plots for the time to transmit good messages ANOVA are shown in Figures 123 – 127.

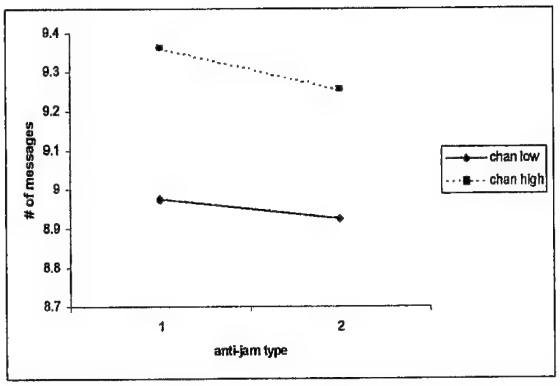

Figure 123. All messages.

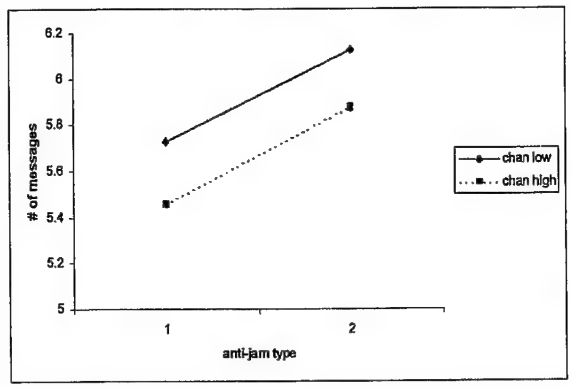

Figure 124. Priority 1.

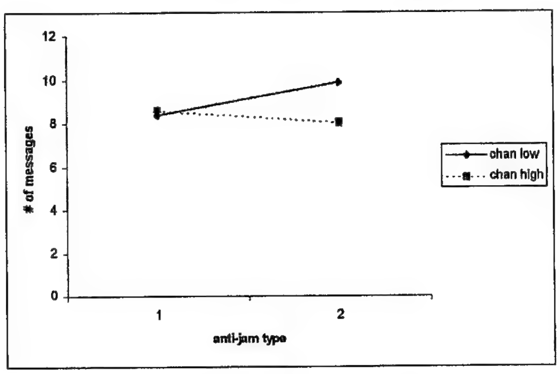

Figure 125. Priority 2.

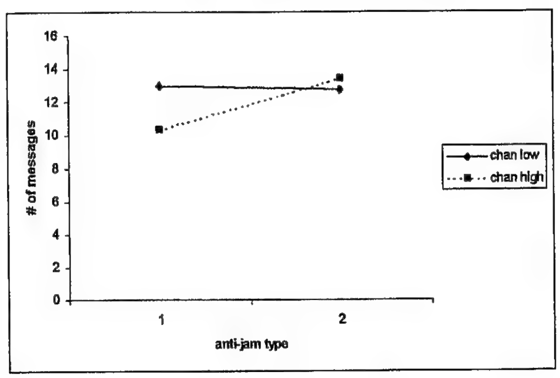

Figure 126. Priority 3.

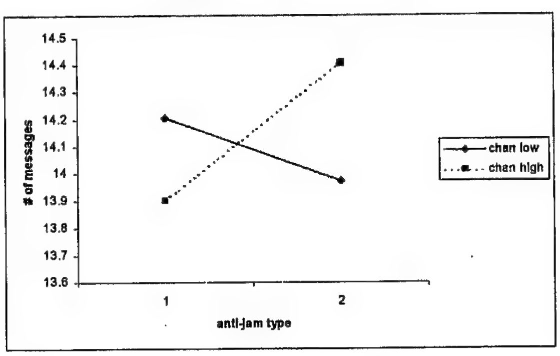

Figure 127. Priority 4.

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